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Ethylene Oxide Control Technology Development for Hospital Sterilizers

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16. ABSTRACT The report discusses the development of ethylene oxide (EO) control technology for hospital sterilizers. Hospitals sterilize heat-sensitive items in gas sterilizers that use a mixture of EO (12 wt %) and a chlorofluorocarbon (CFC) (88 wt %). The active sterilizing agent is EO. The CFC is added as a flameproofing diluent. Two potential sterilizer emission control systems were tested: catalytic oxidation and acid hydrolysis. In catalytic oxidation, relatively dilute mixtures of air and EO (12/88) are passed through a catalyst bed at 149-177 C. The EO is oxidized to CO2 and water; the CFC passes through unchanged. Field tests showed that the EO destruction efficiency of the control device, installed in a hospital, was 99+% of the EO reaching the device. However, 61-78% of the EO was absorbed by the water of the once-through water-sealed vacuum pump. There was no detectable decomposition of the CFC. In acid hydrolysis, EO is hydrolyzed to ethylene glycol using H2SO4 (the CFC is unaffected). A full-scale system was tested under laboratory conditions, simulating a system that could be used for hospital sterilizers. The tests showed that the EO destruction efficiency was 99.9-99.999% of the EO reaching the device. However, 45-60% of the EO was absorbed by the ethylene glycol used in the closed-circuit liquid-ring vacuum pump. Each system has significant advantages and limitations.

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Ethylene Oxide	Sulfuric Acid	Stationary Sources	07C
Sterilizing		Hospital Sterilizers	06I
Medical Equipment		Catalytic Oxidation	06L
Oxidation		Acid Hydrolysis	07B
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ETHYLENE OXIDE CONTROL TECHNOLOGY DEVELOPMENT FOR HOSPITAL STERILIZERS

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Abstract

Ethylene Oxide (EO) has been identified as a toxic air pollutant and was designated as an Intent to List compound in the Federal Register in early 1986. Two of the uncontrolled emission sources of EO are hospital and clinical sterilizers. Over 400 Mg/year (400 TPY) are estimated to be released to the atmosphere each year from these sources.

The EPA Air & Energy Engineering Research Laboratory at Research Triangle Park, N. C. conducted an evaluation of potential concepts to control emissions from hospital and clinical sources in mid 1986. Two potential sterilizer emission control systems were tested, including a low temperature catalytic oxidization system at a hospital, and a pilot acid hydrolysis system. The test results concluded that both systems exhibited destruction efficiencies of approximately 99 percent of the EO that entered the control device.

Hospitals sterilize heat sensitive items in gas sterilizers which use a mixture of EO (12 wt %) and a chlorofluorocarbon (CFC) (88 wt %). The active sterilizing agent is EO. The CFC is added as a flameproofing diluent. In the catalytic oxidation system, the mixtures of air and 12/88 are passed through a catalyst bed at 149-177° C. where the EO is oxidized to CO_2 and water. In the second system based on acid hydrolysis, EO is hydrolyzed to ethylene glycol using sulfuric acid. The acid hydrolysis system was tested in a laboratory using simulated hospital sterilization conditions.

This report summarizes the findings of these evaluations and defines the viability of the respective processes for controlling hospital sterilizer emissions.

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CONVERSION FACTORS (METRIC)

Where the metric equivalent is not given in the text of this report, the following metric conversion factors may be used.

From	To	Multiply By
feet (ft)	meters (m)	0.305
gallons (gal)	liters (l)	3.785
pound (lb)	kilogram (kg)	0.454
pounds/sq in. (psi)	kilopascal (kPa)	6.894
sq feet (ft^2)	sq meter (m^2)	0.093
cu feet per minute (cfm)	cu meter per sec (m^3/sec)	0.00047
in. Hg (60°F)	pascal (Pa)	3376.38
in.	meters	0.254
ft^3	cu meters (m^3)	0.028
gpm	liters per min (LPM)	378

To convert	To	
degree Fahrenheit (°F)	degree Celsius (°C)	$t_c° = (t_f°-32)/1.8$

SECTION 1.0

INTRODUCTION

Ethylene oxide (EO) has been identified as a major toxic air pollutant. The Office of Air Quality Planning and Standards (OAQPS) designated EO as an Intent to List Compound in the Federal Register in early 1986. One of the major uncontrolled sources of EO emissions is hospital and clinic sterilizers. Over 400 Mg/year are estimated to be released to the atmosphere each year from these sources.

AEERL was requested by OAQPS to assist in the identification, development, and evaluation of viable control options for EO emissions from medical facility equipment. Phase I of this project (Work Assignment 5) identified three potential devices for the control of EO emissions from hospital and clinical sources. Phase II of this program (Work Assignment 10) involved tests of selected technologies identified in Phase I.

SECTION 2.0

SUMMARY

Phase I of this study involved a review of control requirements and potential control technologies for hospital sterilizers. Phase II involved actual testing of selected technologies identified in Phase I. This report describes the work accomplished during both Phase I and Phase II.

2.1 PHASE I - POTENTIAL SYSTEMS FOR THE CONTROL OF ETHYLENE OXIDE EMISSIONS FROM HOSPITAL AND CLINICAL SOURCES

2.1.1 Review of Hospital Sterilizers

Almost all hospitals sterilize heat-sensitive items in gas sterilizers which use a mixture of ethylene oxide (EO) and a chlorofluorocarbon (CFC), dichlorodifluoromethane. The active sterilizing agent is EO. The CFC is a flame-proofing diluent. This mixture, which is 12% by weight EO and 88% by weight CFC, is referred to as 12/88.

Hospital sterilizers are essentially enclosed chambers which can be pressurized with 12/88 to sterilize medical equipment. At the conclusion of the sterilization phase, the chamber is evacuated using a vacuum pump and brought to atmospheric pressure by introducing clean, filtered air. The combination of evacuation and air flushes is repeated. After the last air wash, the chamber door is opened, and the sterile products are removed and placed in an aeration cabinet. The purpose of aeration is to allow any residual EO to diffuse out of the sterilized articles.

2.1.2 Ethylene Oxide Emissions

In the absence of control systems, EO emissions come primarily from four sources, the chamber vacuum pump (75-95% of the total emission), the aeration cabinet (5-25%), the sterilizer door area (varies widely), and the EO storage tanks (from accidental leaks). If the vacuum pump is a once-through, water-sealed pump, substantial quantities of EO (60-80% of the total emission) can be discharged to the sewer in the vacuum pump water.

2.1.3 Potential Control Technologies

The chemical reactions of EO and dichlorodifluoromethane were reviewed to evaluate sterilizer emission control options. Catalytic oxidation and acid hydrolysis were shown to be especially suitable. The following selection criteria were developed for EO control technology options (in order of priority): (1) cost, (2) effectiveness and environmental safety, (3) state of development, (4) complexity, (5) space requirements, and (6) safety.

Nine potential control options were examined. Six options were eliminated for the following reasons: carbon adsorption (high operating cost), thermal incineration (toxic by-product), condensation (explosion hazard), ozonation (high cost), corona discharge (toxic by-product), and ultraviolet photolysis (toxic by-product).

2.1.3.1 Catalytic Oxidation--

A control system has been developed in which relatively dilute mixtures of air and EO (12/88) are passed through a catalyst bed at 300°-350°F. The EO is oxidized to carbon dioxide and water; the CFC passes through unchanged. The system is characterized by relatively high flow rates (500-1,000 cfm*) and relatively dilute concentrations of EO (5-500 ppm). The system is designed to treat EO emissions in the sterilizer exhaust and those in the ventilation air from the aeration cabinets and other areas. The system has had 2 years of apparently trouble-free operation at a hospital in Philadelphia. The unit is claimed to be 99.9% efficient in controlling EO.

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*Readers more familiar with metric units may use the conversion factors provided at the end of the front matter.

2.1.3.2 Acid Hydrolysis--

Another control system has been developed which consists of a countercurrent packed column in which EO (in 12/88) is hydrolyzed to ethylene glycol using sulfuric acid at pH 1 (the CFC is unaffected). The system is characterized by relatively high concentrations of EO (250,000 ppm) and very low and highly variable flow rates (0.1-5 cfm). Many industrial-sized units have been installed, and test data on these units show that they are 99+% efficient.[1,2] A hospital system was installed in March 1987. Another type of acid hydrolysis system has been developed in which EO is bubbled through diffusers into aqueous sulfuric acid. A unit of this kind has been designed for hospitals and is claimed to be 99.2% efficient.

2.1.3.3 Adsorption/Reaction--

Some exploratory work has been done on a proprietary process which uses a combination of adsorption and reaction. The process is in the developmental stage and is not ready for full-scale application.

2.2 PHASE II - EVALUATION OF ETHYLENE OXIDE CONTROL TECHNOLOGY FOR HOSPITAL STERILIZERS

Two potential control technologies, catalytic oxidation and acid hydrolysis were selected for testing. Both systems demonstrated very high efficiencies (99+%) in destroying EO emissions discharged from hospital sterilizers. However, only the catalytic oxidation system can treat EO emissions from hospital aerators, which typically account for 5-10% of all EO emitted.

2.2.1 Field Tests of Catalytic Oxidation System

Field tests were performed to measure the EO destruction efficiency of a catalytic oxidation system which had been installed in a hospital. This system handled emissions from the sterilizer vacuum pump, an aeration cabinet, the sterilizer door area, and the EO storage tank area. Two types of experiments were performed; one type involved the treatment of the sterilizer discharge, and in another type, sterilizer gas was added directly to the system.

In the sterilizer discharge experiments, the observed EO destruction efficiency was high, greater than 99%. As expected for this type of system, the concentration of EO entering the catalyst system varied widely, reaching a maximum of 400-450 ppm. Flow rates were about 500 cfm.

In the sterilizer discharge experiments, only about 10-13% of the EO in the sterilizer actually reached the catalyst system. A major fraction of the EO was absorbed by the water which was used in the once-through, water-sealed vacuum pump. Analysis of the aqueous discharge indicated that an unexpectedly large proportion of the EO in the sterilizer (61-78%) was discharged to the sewer in the water from the vacuum pump.

Additional experiments were performed in order to supplement the analytical data obtained during sterilizer discharge. EO was added (at a controlled rate) to the system at a point located upstream from the catalyst. Sufficient EO was added to bring the concentration of the stream to selected levels of EO. Three levels, 125-250 ppm, 400-600 ppm, and 750-1,500 ppm were tested. The results of these experiments indicated high catalyst efficiencies, 99.8% or better.

An important significance of the EO addition experiments is that they demonstrated that the catalytic oxidation system was capable of operating very efficiently at concentrations of sterilizer gases comparable to those developed if the total discharge from the sterilizer were directed into the system.

All of the tests were performed using the common sterilizing gas mixture (12/88) which is 12% ethylene oxide and 88% chlorofluorocarbon (dichlorodifluoromethane). Separate tests demonstrated that there was no detectable decomposition of the chlorofluorocarbon under the conditions of the catalytic oxidation.

2.2.2 Laboratory Tests of Acid-Hydrolysis System

A full-scale acid-hydrolysis system was tested under laboratory conditions which closely simulated a system that could be used for hospital sterilizers. This system handled only the discharge from the vacuum pump, and was not designed to handle aeration discharges or other airflows containing low concentrations of EO. The tests demonstrated that the system was very efficient, destroying 99.99-99.999% of the EO.

Four tests involved actual discharges from a hospital-type sterilizer and three tests involved the direct addition of EO (12/88). In the sterilizer discharge studies, only about 25-26% of the EO in the sterilizer was observed to reach the system. Evidence indicated that a major fraction of the EO was absorbed by the ethylene glycol used in the closed-circuit, liquid-ring vacuum pump, thus reducing the amount of EO reaching the system. The concentrations of EO reaching the system were 20,000-140,000 ppm (2-14%) and the flow rates were 0.1-1.5 scfm.

Of the EO reaching the system, more than 99.99% was removed from the gaseous stream.

Ethylene oxide (12/88) was also added directly to the system in order to determine efficiencies at levels of flow rate near the maximum for which the system was designed (2.5 cfm). These studies also demonstrated the high efficiency of the hydrolysis system, greater than 99.999%.

2.2.3 Cost Effectiveness

Estimated costs for the two potential control technologies, catalytic oxidation and acid hydrolysis are as follows:

	Catalytic Oxidation	Acid Hydrolysis
Capital costs		
Equipment	$25,000-$40,000	$15,000-$20,000
Installation	$ 5,000-$10,000	$ 4,000-$ 6,000
Total equipment cost	$30,000-$50,000	$19,000-$26,000
Annual operating cost	$ 5,700-$16,000	$ 600-$ 6,000

In considering the relative costs of these systems, the advantages and limitations of each should be considered. The catalytic oxidation system is capable of treating all of the gaseous EO emissions from the sterilizer vacuum pump, the aeration cabinets, the sterilizer door area, the EO storage tanks, and any other areas that can be ventilated. However, there are other EO emission problems related to the relatively large amounts of EO (60-80% of sterilizer charge) which can be lost to the environment through the aqueous discharge from once-through, water-sealed vacuum pumps. Recirculating vacuum pumps may prevent this emission, but most hospital sterilizers are apparently not currently equipped with recirculating vacuum pumps. (Installation of recirculating vacuum pumps will result in costs nearer the high side of the above capital cost estimates.) Furthermore, even with recirculating vacuum pumps, the substantial absorption of EO into the recirculating fluid produces a potential emissions problem.

The present acid-hydrolysis system can only treat the direct discharge from the sterilizer (through the vacuum pump). EO emissions from the aeration cabinets, sterilizer door area, and other dilute emissions could probably not be handled efficiently by the acid-hydrolysis systems. Recirculating vacuum pumps would ordinarily be used with acid hydrolysis systems; this would eliminate an immediate discharge of EO-contaminated sealant liquid, but methods of disposing of the contaminated sealant liquid would need to be devised.

As Table 2-1 shows, the catalytic oxidation system has a greater overall EO destruction efficiency than the acid-hydrolysis system. This is primarily because the acid-hydrolysis system cannot treat discharges from the aeration chamber or other dilute sources.

TABLE 2-1. COMPARISON OF SYSTEM EFFICIENCIES

EO source	Approximate percentage of total EO emissions[a]	Emission reduction potential[b] Catalytic oxidation (%)	Acid hydrolysis (%)
Sterilizer[c]	75-95	99.5+	99.9+
Aerator	5-25	99.5+	0.0
Sterilizer room ventilation air	< 1	99.5+	0.0
Total reduction potential		99.5+	75-95

[a] The estimated percentages of total EO emissions were developed in Phase I of this program.

[b] The catalytic oxidation system has a greater overall EO emission reduction potential primarily because the acid hydrolysis system cannot treat the discharge from the aerator or other dilute sources.

[c] In the sterilizer discharge experiments described in this report, approximately 75 percent of the EO from the sterilizer was absorbed by the vacuum pump fluids and did not reach the control systems. However, other experiments demonstrated that the control systems were capable of handling the full discharge of the sterilizer. The efficiencies indicated for both types of control devices are based on the assumption that the vacuum pump fluids are not discharged.

2.3 REFERENCES FOR SECTION 2

References which discuss the efficiency of industrial-sized acid-hydrolysis units are as follows:

1. Buonicore-Cashman Associates (BCA), Inc. Certification Testing Report. BCA Project No. 85-260, January 1985.

2. Desai, P. R. Performance Test Report, DEOXX™ Ethylene Oxide Detoxification System. Chemrox Project No. 85-260, October 1985.

SECTION 3.0

CHARACTERIZATION OF HOSPITAL STERILIZERS

This section of the report provides a brief description of the sterilizing agent used in hospital sterilizers and a description of sterilizer operations. The sources of ethylene oxide emissions are also identified.

3.1 THE STERILIZING AGENT

Almost all hospitals sterilize heat-sensitive items in gas sterilizers which use a mixture of EO and a chlorofluorocarbon (CFC), dichlorodifluoromethane. The active sterilizing agent is EO. The CFC is a flameproofing diluent. The mixture, which is 12% by weight EO and 88% by weight CFC, is referred to as 12/88. The composition of 12/88 on a volume basis is 277,000 parts per million by volume (ppmv) EO and 723,000 ppmv CFC. Although 12/88 is a more costly sterilant gas than pure EO, it has the advantage of being nonexplosive and nonflammable. Pure EO is explosive in concentrations from 3-100%.

Pure EO is used only rarely by hospitals and only for very small sterilizers. In other, nonhospital applications where pure EO is used, the sterilizing chambers must be installed in explosion-proof rooms.

3.2 STERILIZER OPERATIONS

Hospital sterilizers are essentially enclosed chambers constructed of stainless steel which can be pressurized to about 10 psig and evacuated to about 26 in. of mercury. A photograph of a typical sterilizer is shown in Figure 3-1. Also shown is a cart and tray system in which the articles to be sterilized are placed. A schematic of a hospital sterilizer is shown in Figure 3-2.

The articles to be sterilized are loaded into the chamber, and the doors are closed. A diagram of the sterilization pressure cycle is shown in Figure 3-3. The gauge pressure in the chamber is reduced to 22-26 in. of mercury vacuum using a vacuum pump. This portion of the cycle is called presterilization conditioning (Figure 3-3). The chamber temperature is then adjusted to 28°-49°C, and the relative humidity is raised to about 40-60% by injecting steam. After equilibrium is achieved, 12/88 is pumped into the chamber to achieve the desired concentration of EO, typically about 200,000 ppm. A typical chamber pressure is about 10 psig (Figure 3-3). The chamber is held at this pressure for 2-16 hr (typically 2-3 hr). This is the sterilization phase of the cycle. At the conclusion of the sterilization phase, the chamber is evacuated using a vacuum pump until the gauge pressure within the chamber reaches 22-26 in. of mercury vacuum. This evacuation phase typically lasts about 10 min. The pressure in the chamber is brought to atmospheric pressure by introducing clean, filtered air. This portion of the cycle lasts about 2 min. The combination of evacuation and air flushes is then repeated from 2-4 times to remove as much of the EO from the articles as possible.

After the last air wash, the chamber door is opened, and the sterile articles are removed and placed in an aeration chamber. The purpose of aeration is to allow any residual EO to diffuse out of the sterilized articles.

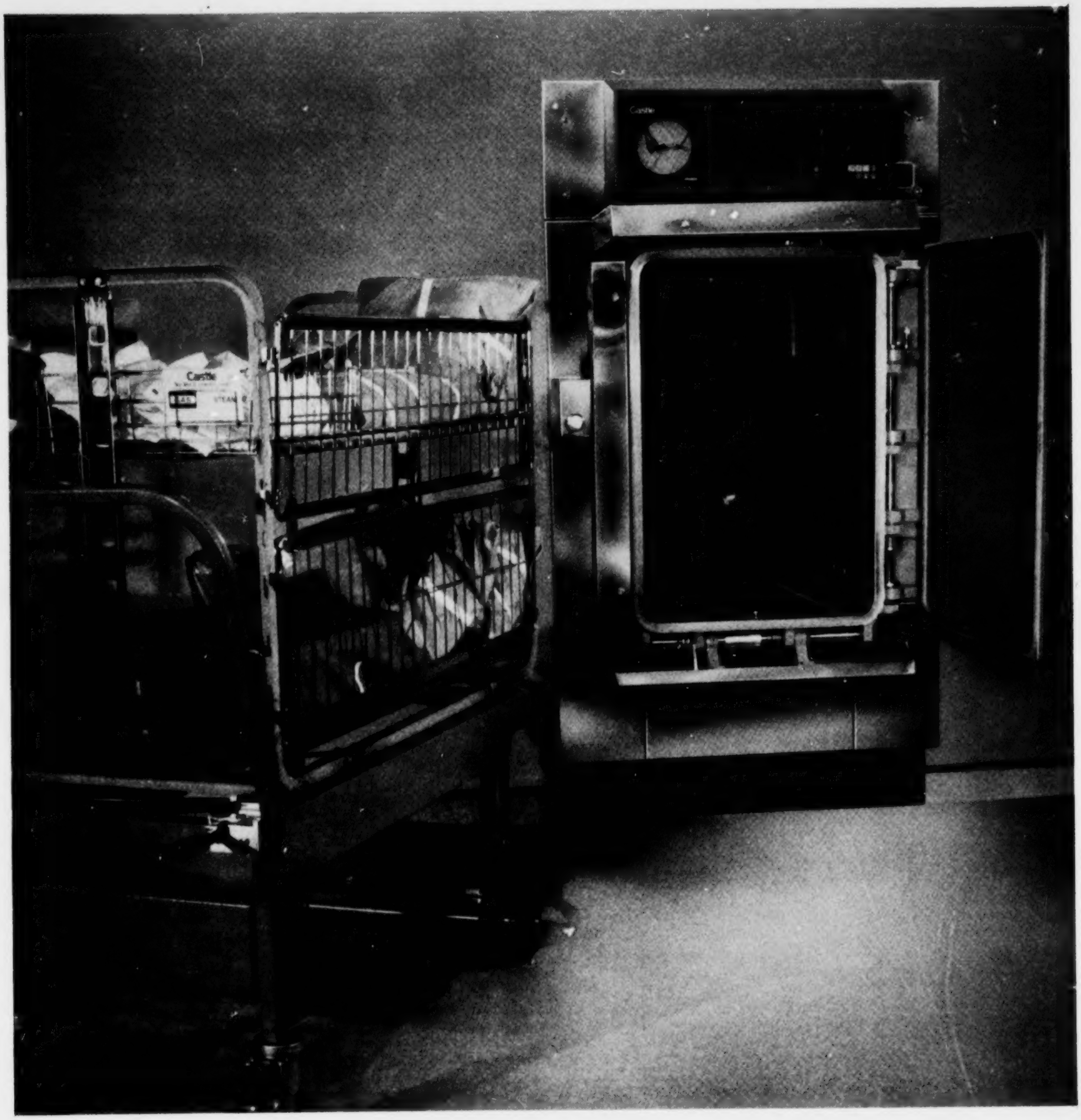


Figure 3-1. Typical hospital sterilizer showing cart and tray system.

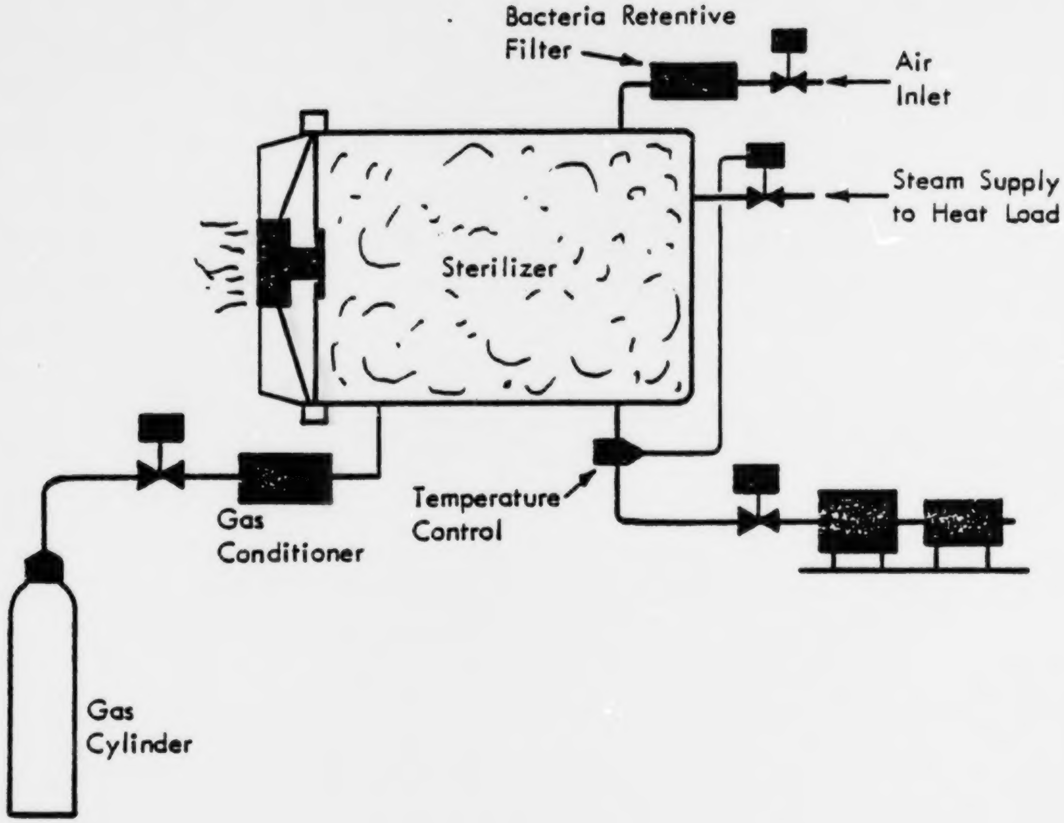
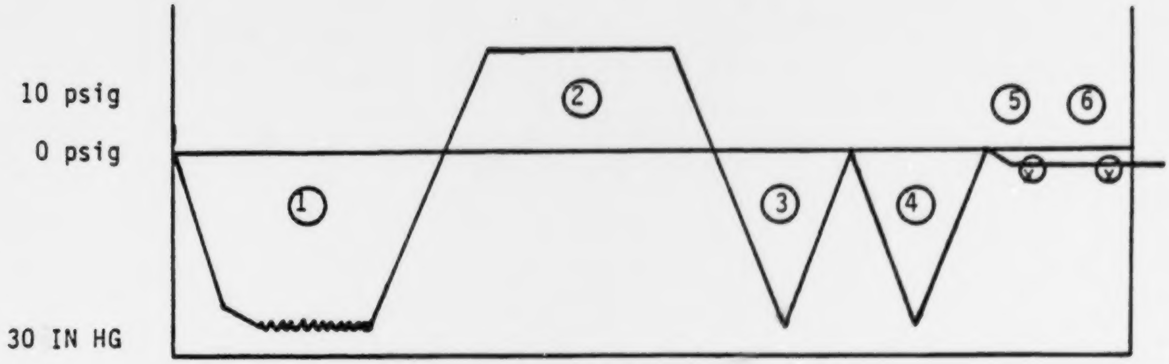

Bacteria Retentive Filter
Air Inlet
Steam Supply to Heat Load
Sterilizer
Temperature Control
Gas Conditioner
Gas Cylinder

Figure 3-2. Schematic of hospital sterilizer.



1. PRESTERILIZATION CONDITIONING
2. STERILIZATION/EO EXPOSURE
3. FIRST EXHAUST VACUUM
4. SECOND EXHAUST VACUUM
5. AND 6. AIR FLUSH/VENTILATION

x BUZZER ALARM

Figure 3-3. Ethylene oxide process sterilization cycle.

The length of time necessary to remove residual EO from the sterilized items depends on the composition of the sterilized materials, their physical dimensions or surface area, the packaging material, the sterilization parameters used, and the temperature and air exchange rate of the aerator. The higher the residue level, the longer the required aeration time. The amount of absorbed EO in rubber and plastic components can range as high as 35,000 ppm (3.5%), as indicated in Table 3-1. An EO-sterilized item made from natural rubber requires a longer aeration time than the same item made from polyethylene because rubber absorbs more EO. Items that are large, have thick tubing, or have extensive surface area absorb greater quantities of EO and require longer times for aeration than small, thin-tubed, low-surface-area items. Typical aeration times range from 1-32 hr.

TABLE 3-1. THE EXTENT OF ETHYLENE OXIDE ABSORPTION AS A RESULT OF STERILIZATION

Material	Residue level (ppm)
Polyvinyl chloride	10,0000,000
Polystyrene	15,0005,000
Polyethylene	5,0000,000
Polypropylene	13,0008,000
Natural rubber	20,0005,000
Synthetic rubber	18,0002,000
Silicone rubber	15,0000,000

Source: Central Supply Department, Menorah Medical Center, Kansas City, Missouri.

3.3 ETHYLENE OXIDE EMISSIONS

Figure 3-4 shows the typical layout of a central EO sterilization room at a hospital. The sterilizers and aerators are generally flush-mounted through a wall enclosing a "core room" behind the sterilizers and aerators. The figure shows one sterilizer and one aerator, but there can be several of each

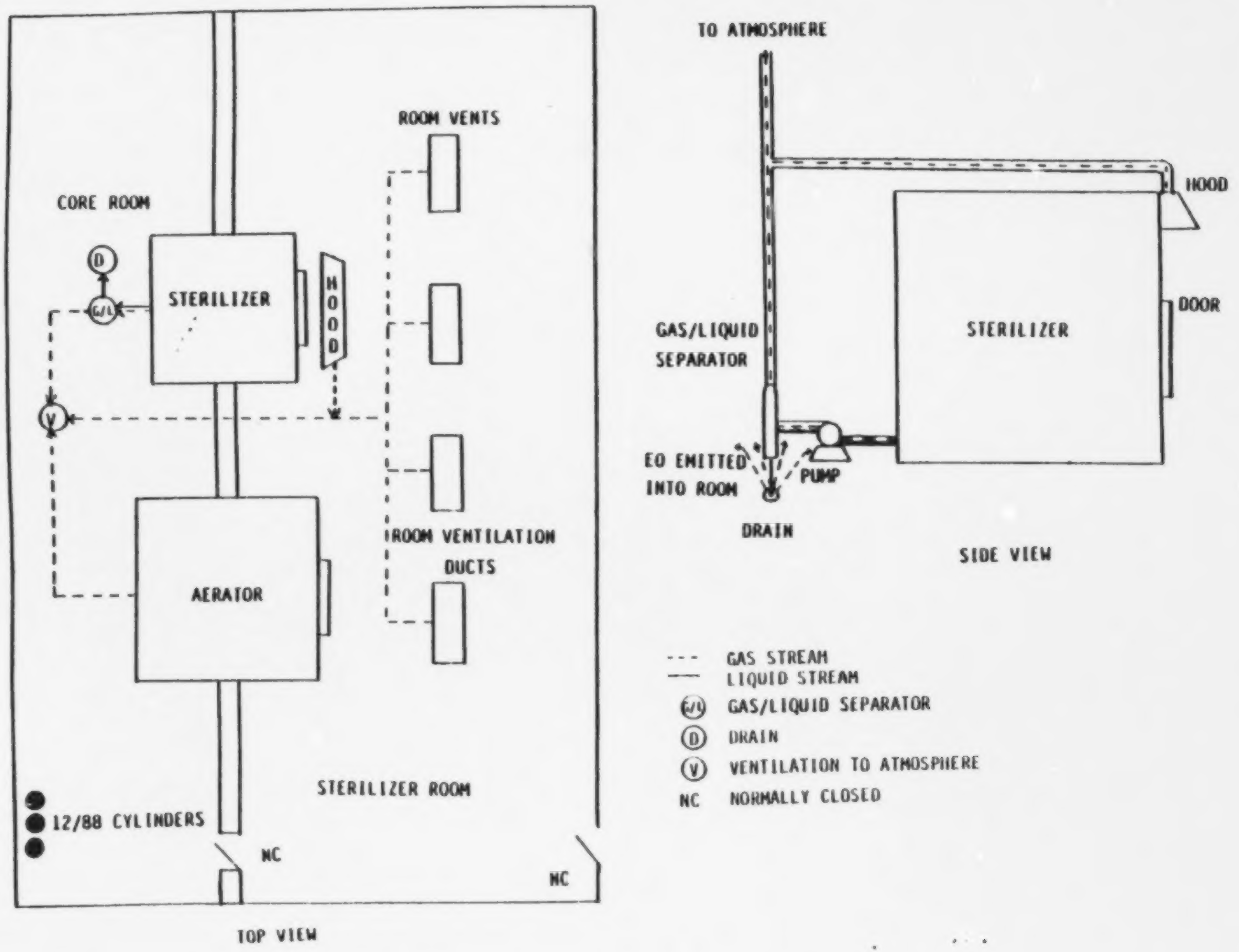

TO ATMOSPHERE
ROOM VENTS
CORE ROOM
D
G/L
STERILIZER
HOOD
V
ROOM VENTILATION DUCTS
AERATOR
STERILIZER ROOM
12/88 CYLINDERS
NC
NC
TOP VIEW
HOOD
DOOR
GAS/LIQUID SEPARATOR
STERILIZER
EO EMITTED INTO ROOM
PUMP
DRAIN
SIDE VIEW
--- GAS STREAM
— LIQUID STREAM
G/L GAS/LIQUID SEPARATOR
D DRAIN
V VENTILATION TO ATMOSPHERE
NC NORMALLY CLOSED

Figure 3-4. Typical hospital sterilizer room showing ethylene oxide emission sources.

along the wall depending on the size of the hospital. The core rooms contain the vacuum pumps, drain lines, ventilation ducting, and often the 12/88 tanks. The core room is accessible by a door from the main sterilizer room. This door remains closed except during cylinder changes, pump maintenance, etc. Core rooms tend to be small with little unused floor space. Because the sterilizer is maintained at 130°F throughout the sterilization cycle, the core room is usually much hotter than typical room temperature. Figure 3-4 also shows the major EO emission points: the sterilizer vent, the drain area, the sterilizer door, and EO cylinder leaks. The sterilizer and aerator are directly connected to ventilation ducts, while emissions from around the sterilizer door and sterilizer room ambient air are hooded and vented to the duct. Drain emissions can be hooded, but more often, the EO is allowed to enter the core room where it may be removed by ventilating the core room airspace.

A more detailed discussion of each EO emission source follows.

3.3.1 The Sterilizer Vent and Drain

The major source of EO emissions (70-95% of the total) is the chamber vacuum pump during the evacuation phase. These vacuum pumps are typically once-through liquid-ring pumps that use water as the working fluid. A mixture of water and chamber gas is expelled from the pump. The EO and CFC are released and emitted to the atmosphere. The water is sent to a sewer drain. Building codes require a 1-in. air break between the pump and the sewer drains. Some EO will desorb and be emitted to the atmosphere as the solution falls through the air break.

The fate of EO remaining in solution after the air break is uncertain. The EO could desorb from the liquid into the headspace of the sewer pipes and be emitted at leaks in sewer lines, pipe connections, and at other points in the sewer system. Another possible fate is chemical conversion within the sewer system. A wide variety of reactions is possible depending upon the exact chemical composition of the sewage and on physical conditions within the sewer. It is expected that any EO reaching the publicly owned treatment works (POTW) would be emitted during the aeration phases of treatment.

3.3.2 The Aeration Chamber

A second emission source is the aeration cabinet. As EO diffuses out of the sterile articles, it is emitted to the atmosphere via the cabinet vent. The amount of EO emitted from this source is directly related to absorbancy of the sterilized materials. Typically, plastic and rubber items absorb large quantities of EO. Table 3-1 shows the residual EO levels in different types of plastic and rubber after sterilization. If a sterilizer load contained a high proportion of these materials, the EO emissions from the aerator would be significant.

3.3.3 The Sterilizer Door

Small amounts of EO are emitted during the sterilization phase from leaks in the door seals. Also, after the evacuation cycles there is still some EO remaining in the sterilizer. This quantity is emitted when the door is opened to remove the sterilized articles. These two sources are relatively small in comparison to the sterilizer vent and aerator emissions.

3.3.4 The EO Storage Tanks

The storage tanks are pressure vessels, and no emissions should occur during routine operation. However, emissions may occur during cylinder changes and from gas cylinders, transfer lines, and valves during emergency or upset conditions.

3.4 MODEL STERILIZER PARAMETERS

Based on information obtained in a survey of hospitals and sterilizer manufacturers, parameters characteristic of three sizes of hospital sterilizers were developed. These model sterilizer parameters are presented in Table 3-2.

TABLE 3-2. MODEL STERILIZER PARAMETERS

	Sterilizer size		
	Small	Medium	Large
1. Sterilizer parameters			
Chamber volume, ft^3	8.8	30	71
Cycles per year	365	400	250
Cycle duration, min	180	240	240
Cycle processes (duration, min):			
Preconditioning/prevacuum	35-40	35-40	35-40
Sterilizer gas charge	5	5	5
Sterilizer/exposure	120	180	180
Postvacuum/exhaust	20	20	20
2. Chamber environmental conditions			
Temperature, °F			
Chamber	130	130	130
Exhaust stream	80-85	80-85	80-85
Relative humidity, %	50	50	50
Pressure, psig	8-10	8-10	8-10
Preconditioning vacuum, in. Hg	22-26	22-26	22-26
Postexhaust vacuum, in. Hg	22-26	22-26	22-26
Chamber EO concentration, ppm	200,000	200,000	200,000
3. Sterilizer gas characteristics			
Maximum EO concentration at exhaust, ppm	200,000	200,000	200,000
EO consumption per cycle, lb	0.31	1	2.4
EO consumption per year, lb	113	400	900

3.5 FLOW RATES AND EO EMISSIONS FROM MODEL STERILIZERS

Based on the model sterilizer parameters, the sterilizer flow characteristics were calculated. The results of these calculations are shown in Figures 3-5 through 3-10.

The data can perhaps best be explained by means of an example: in Figure 3-9, at time zero a large hospital sterilizer (71-ft^3 chamber) has been pressurized to about 10 psig. The sterilization cycle is complete, and the vacuum pump is turned on. The flow rate at the beginning of the cycle is about 0.0145 m^3/sec or about 31 ft^3/min. This flow rate decreases exponentially with time until, at the end of the first vacuum exhaust cycle, the rate is about 0.0015 m^3/sec or about 3.2 ft^3/min.

After ventilation air has entered the sterilizer, the pressure returns to atmospheric pressure, and the pump begins again. The flow rate is about 0.009 m^3/sec (19 ft^3/min) at this point and decreases exponentially in about 8 min to about 0.0015 m^3/sec (3.2 ft^3/min).

Corresponding EO concentrations in the exhaust of this sterilizer are shown in Figure 3-10.

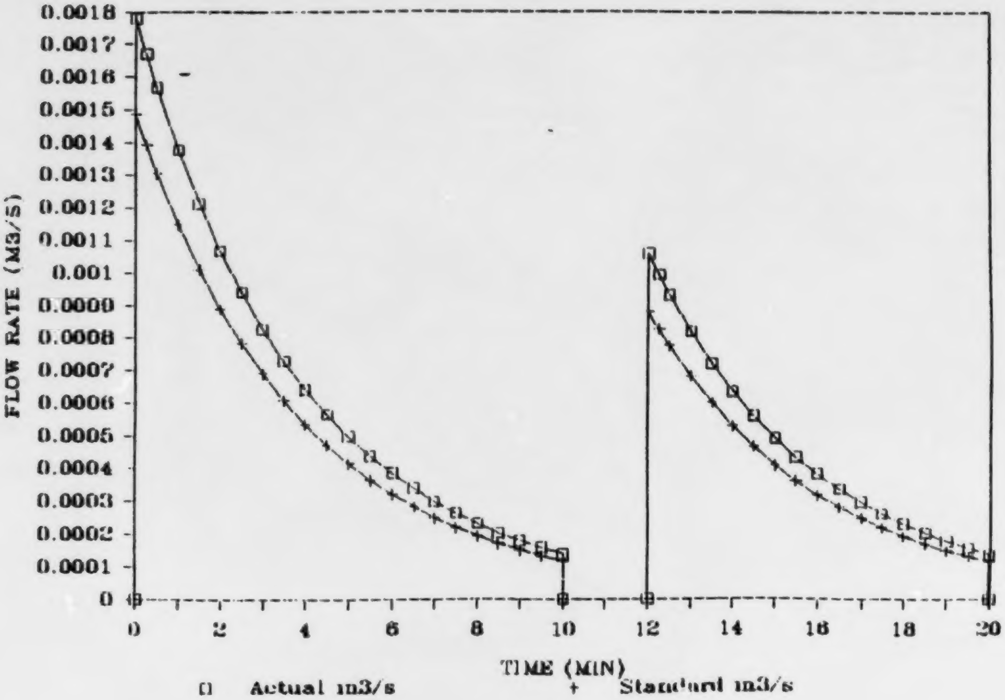


Figure 3-5. Gas flow rate versus time (8.8-ft^3 chamber).

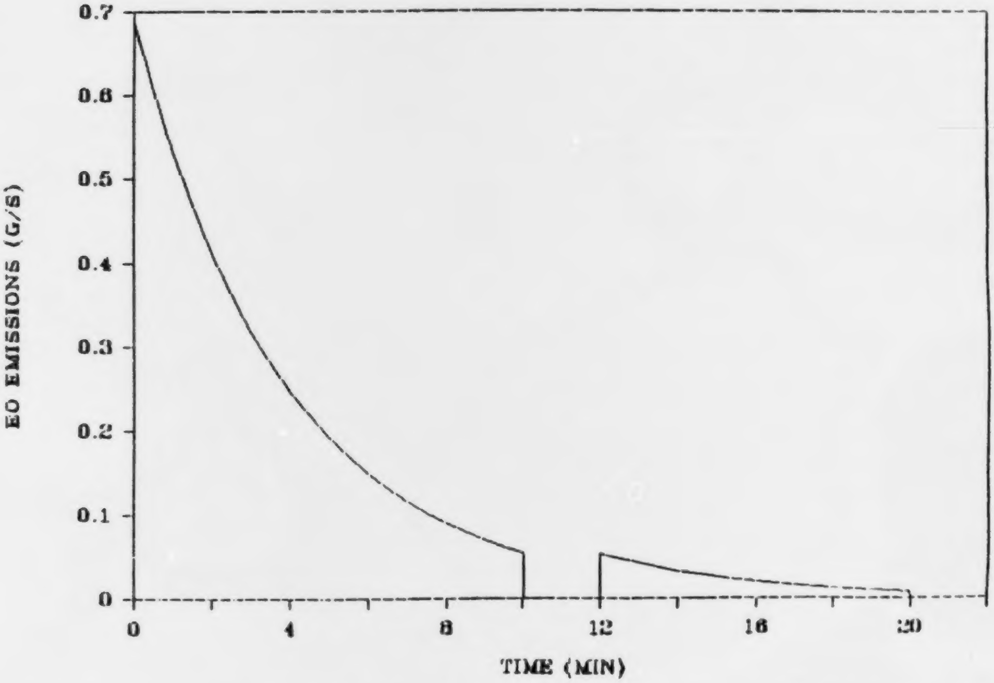


Figure 3-6. Ethylene oxide emissions versus time (8.8-ft^3 chamber).

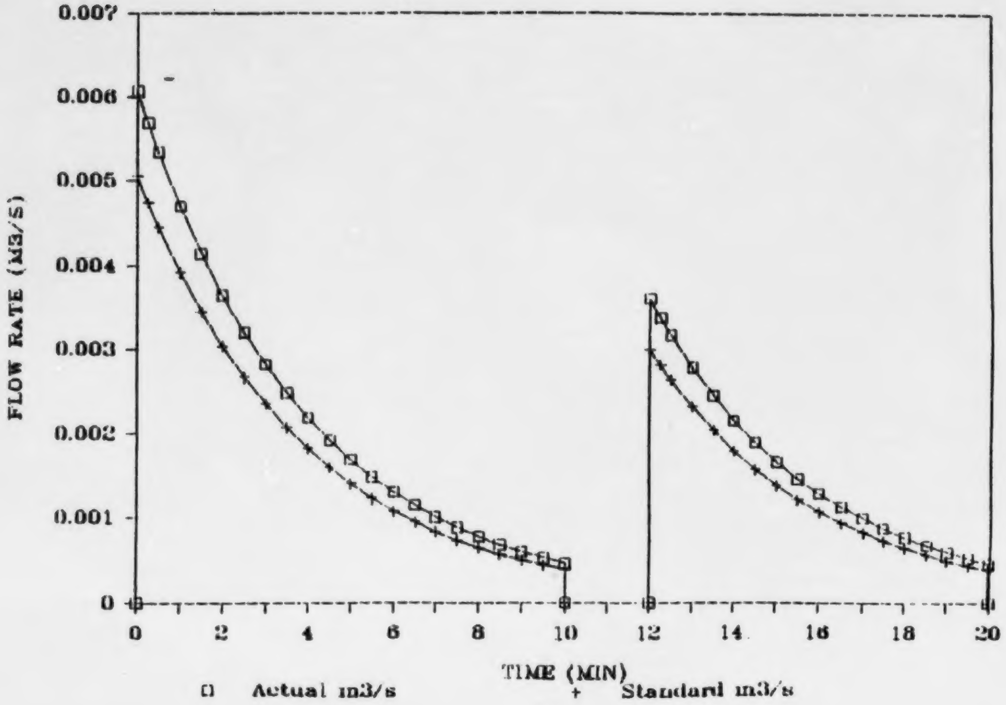


Figure 3-7. Gas flow rate versus time (30-ft^3 chamber).

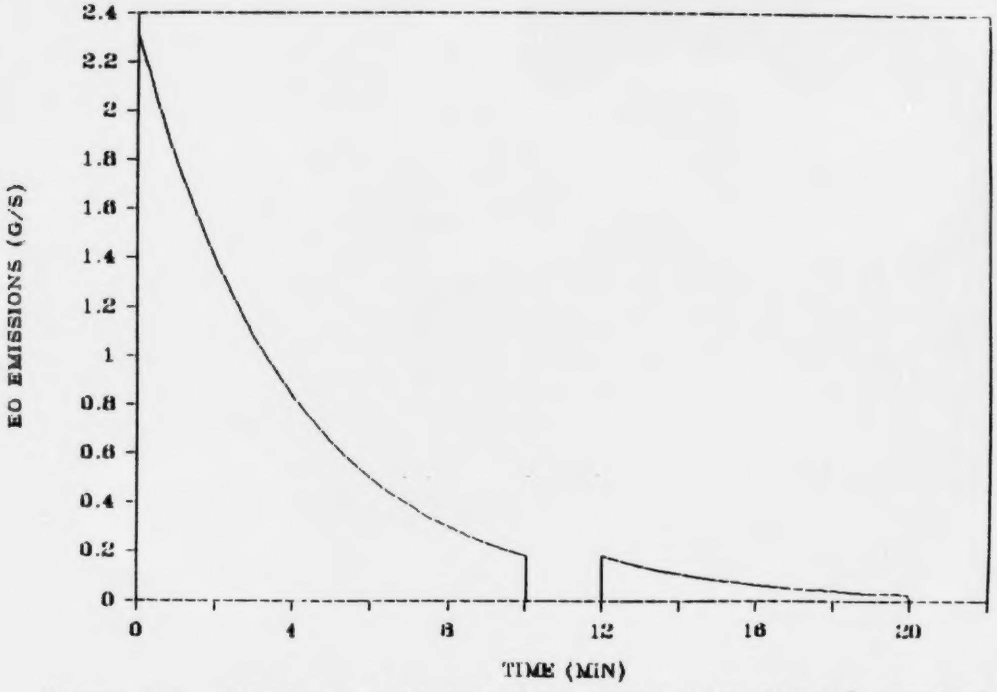


Figure 3-8. Ethylene oxide emissions versus time (30-ft^3 chamber).

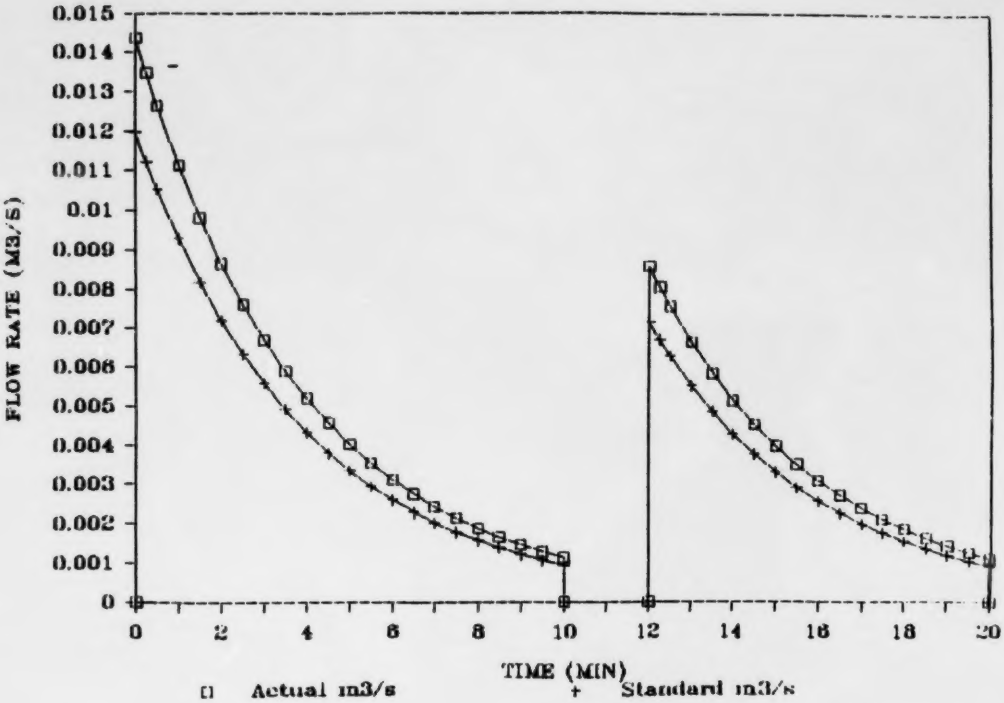


Figure 3-9. Gas flow rate versus time (71-ft^3 chamber).

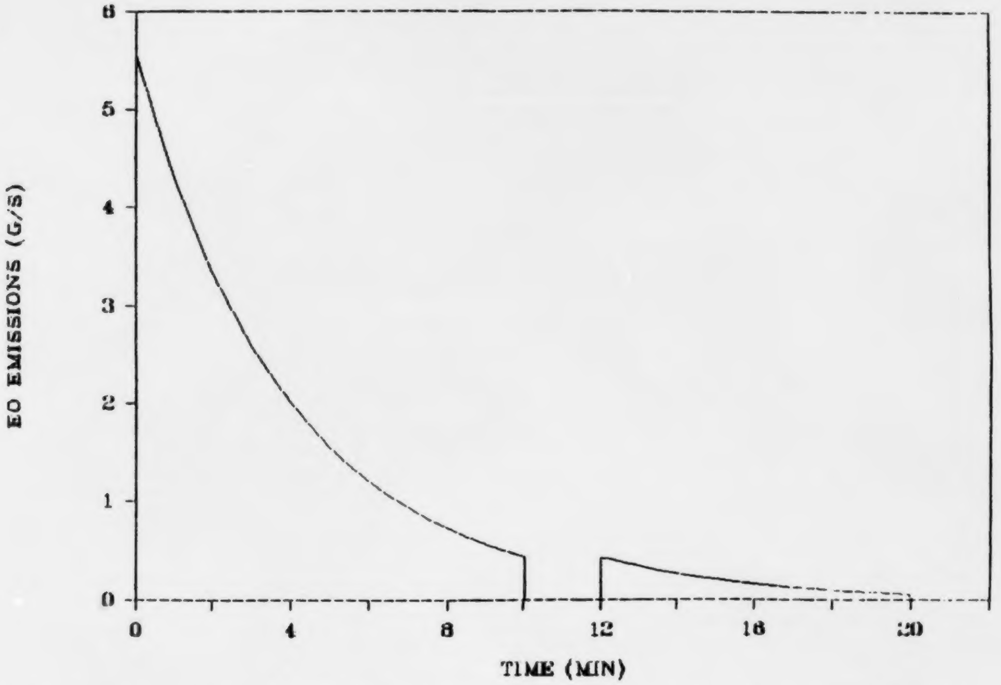


Figure 3-10. Ethylene oxide emissions versus time (71-ft^3 chamber).

SECTION 4.0

SELECTION OF ETHYLENE OXIDE CONTROL OPTIONS

The selection criteria that were developed for EO control options are listed in Table 4-1. The cost and effectiveness of the system (environmental safety) were given the highest priority with lesser but equal emphasis placed on the stage of development, complexity, space requirements, and safety.

4.1 SELECTION CRITERIA FOR EO EMISSION CONTROL OPTIONS

4.1.1 Costs

Costs to be considered are the capital cost, installation costs, and operating costs. Installation costs include the substantial costs that could be encountered as a result of retrofit installation into existing hospital sterilizer operations. Walls and ceilings may require removal or adaptation. Substantial piping and ductwork may be required if the control system is located remote from the sterilizers. If the system is at the research stage, the R&D costs of developing the system must be considered. Other important costs are the costs of disposing of any products or by-products of the control process.

4.1.2 Effectiveness/Environmental Safety

The effectiveness of the system is related to environmental safety. The extent to which EO and, to a lesser extent, the CFC are removed is a very critical parameter. Also to be considered are the possibilities of discharging toxic products to the air. A distinct possibility with some Table 4-1

TABLE 4-1. SELECTION CRITERIA FOR STERILIZER CONTROL TECHNOLOGY

Costs

- Capital equipment costs
- Installation costs
- Operating costs
- Costs for disposal of products and by-products
- Required R&D costs

Effectiveness/environmental safety

Air	• Percent EO removal • Percent CFC removal • Absence of toxic by-products • Adaptivity to various flow rates and concentrations
Water	• Magnitude of wastewater disposal problem
Solid waste	• Magnitude of hazardous solid waste disposal

State of development

- Developed
- Developing
- Research stage

Complexity

- Ability to run unattended
- Required maintenance
- Level of technical support
- No startup, shutdown problems

Space requirements

- Location reference to sterilizer
- Size

Safety

- Overall safety of operation

control options is the decomposition of the CFC to toxic gases such as phosgene, hydrogen chloride, and hydrogen fluoride. Similarly, the necessity of disposing of toxic aqueous or solid products must be considered. For acid scrubbing systems, an important aqueous waste is the acidic ethylene glycol solution generated.

4.1.3 Stage of Development

The stage of development of the control option is also important. A system ready for installation in a hospital is obviously of more significance than a concept that has only been demonstrated at the laboratory level.

4.1.4 Complexity

Another important consideration, especially for hospitals, involves the complexity of the system. In most cases, very little chemical engineering expertise is available at hospitals. Therefore, the process should run unattended and require little maintenance. Since the system will operate intermittently, there should be no problems with regard to startup or shutdown.

4.1.5 Space Requirements

Since most control systems will be installed to service existing hospital sterilizers, the space requirements of the control system are critical. Little space is usually available in the sterilizer area, and walls and ceilings may need to be modified, and steam lines and electrical conduits may reed to be installed. Alternatively, it may be necessary to install the system at considerable expense at a location remote from the sterilizer.

4.1.6 Safety

Finally, the system must be capable of functioning safely in regard to all of those personnel who will be involved: sterilizer operators, maintenance workers for the sterilizer and the control process, and all other personnel in the vicinity of the sterilizer and the control process.

4.2 CHEMICAL REACTIONS OF ETHYLENE OXIDE AND DICHLORODIFLUOROMETHANE RELEVANT TO STERILIZER EMISSION CONTROL OPTIONS

The sterilizing gas used in hospital sterilizers contains EO (12% by volume) and dichlorodifluoromethane (88% by volume). In order to assess potential emission control options, the chemical properties and reactions of these gases must be considered. Some pertinent properties are presented in Table 4-2. The two most important reactions with regard to evaluating EO emission control technologies are oxidation and hydrolysis, which are discussed below.

4.2.1 Oxidation

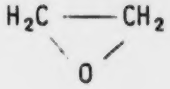
Ethylene oxide can be very easily and completely destroyed by thermal incineration to produce the harmless products carbon dioxide and water (Equation 1).

$$\mathrm{EO + O_2} \xrightarrow[\text{oxidation}]{\text{thermal}} \mathrm{CO_2 + H_2O} \qquad (1)$$

However, under most conditions of thermal oxidation, CFC produces harmful and toxic by-products[1] (Equation 2).

$$\mathrm{CF_2Cl_2 + O_2} \xrightarrow[\text{oxidation}]{\text{thermal}} \begin{array}{ll} \mathrm{COCl_2} & \text{Phosgene} \\ \mathrm{COF_2} & \text{Carbonyl fluoride} \\ \mathrm{HCl} & \text{Hydrogen chloride} \\ \mathrm{HF} & \text{Hydrogen fluoride} \\ \mathrm{CF_4} & \text{Carbon tetrafluoride} \\ \mathrm{Cl_2} & \text{Chlorine} \\ \mathrm{CO} & \text{Carbon monoxide} \end{array} \qquad (2)$$

TABLE 4-2. SOME PERTINENT PROPERTIES OF EO AND DICHLORODIFLUOROMETHANE

Ethylene oxide (EO)	Dichlorodifluoromethane (Freon-12)
	CF_2Cl_2
M.W. 44.04	M.W. 120.92
Flammable gas	Nonflammable gas
b.p. 10.4°C	b.p. -29.8°C
Miscible with water and most organic solvents	Water solubility: 280 mg/L; soluble in organic solvents
Highly reactive	Very inert
Explosive in air (3 to 100 vol %)	Nonexplosive

Catalytic incineration, which proceeds in the presence of a solid-phase catalyst, can be performed at lower temperatures and does not produce harmful CFC by-products (Equations 3 and 4).

$$EO + O_2 \xrightarrow{\text{catalytic incineration}} CO_2 + H_2O \qquad (3)$$

$$CF_2Cl_2 + O_2 \xrightarrow{\text{catalytic incineration}} \text{no reaction} \qquad (4)$$

4.2.2 Hydrolysis

Ethylene oxide can be hydrolyzed under relatively mild conditions to nontoxic products; the CFC is unaffected by these conditions. Ethylene glycol is prepared industrially by the hydrolysis of EO (Equation 5).

$$\mathrm{EO} \xrightarrow[H^+]{H_2O} \begin{array}{ll} \mathrm{HOCH_2CH_2OH} & \text{Ethylene glycol} \\ \mathrm{HO(CH_2CH_2O)_nH} & \text{Poly(ethylene glycols)} \\ (n = 2, 3, 4) & \end{array} \qquad (5)$$

The reaction is conducted in a large excess of water at moderate temperatures to obtain 85-90% ethylene glycol selectivity. The lower polyglycols, diethylene, triethylene, and tetraethylene glycols account for the remainder, the primary by-product being diethylene glycol. The hydrolysis reaction is slow at ambient temperatures, but the speed of the reaction can be increased by addition of heat or acid or basic catalysts.

Other reactions of EO that were considered for potential control technology options are reviewed in Appendix A.

4.3 REFERENCES FOR SECTION 4

1. Sax, N. I. 1984. Dangerous properties of industrial materials.

SECTION 5.0

CONTROL TECHNOLOGY CONCEPTS

Nine techniques were assessed as possible candidates for control of EO emissions from hospital sterilizers. Each technique was examined in terms of its mode of operation, expected efficiency, probable by-products, safety hazards, and general technical feasibility. The data gathered on each technique were evaluated with respect to the selection criteria described in Section 4. Table 5-1 provides a list of the nine criteria evaluated and the results of the evaluation. Based on this evaluation, six concepts were eliminated. A detailed review of these six concepts is presented in Appendix B. The information gathered on the three remaining concepts is presented in Table 5-2. Further details of each concept are described below.

TABLE 5-1. POTENTIAL ETHYLENE OXIDE CONTROL CONCEPTS AND MAJOR OBJECTION FOR HOSPITAL STERILIZER APPLICATION

Control concept	Objection
Acid hydrolysis (scrubbing)	None
Catalytic oxidation	None
Carbon adsorption	High operating cost
Adsorption/reaction	No data
Thermal incineration	Toxic by-product
Condensation	Explosion hazard
Ozonation	High cost
Corona discharge (controlled plasma)	Toxic by-product
Ultraviolet photolysis	Toxic by-product

TABLE 5-2. ETHYLENE OXIDE CONTROL TECHNOLOGIES SUMMARY

Control	Company and location	No. of installations (no. in hospitals)	Primary effluent	Operating principles	Comments
Acid hydrolysis	Chemrox Bridgeport, Conn.	20 (0)	40 wt % ethylene glycol with some sodium sulfate	Countercurrent packed column--acid hydrolysis at pH 1.0 to ethylene glycol accumulation of glycol until 40 wt %, then neutralize and dump.	First hospital system operated July 1987. Design criteria are $10 to 15K, 3 ft x 3 ft x 7 ft, self-sufficient, 99.9% efficient. Whether these will be met is the question. Chemrox has installed many industrial-sized units and have test data showing 99+% efficiency. EO control is their only business.
of 12/88	Damas S. Hackensak, N.J.	27 (0)	30 wt % glycol with some sodium sulfate	Bubbles gas through sulfuric acid solution at pH 1.0. Patented diffuser said to maximize EO transfer into solution where it reacts to form glycol. Accumulation of glycol until 30 wt %, then neutralize and dump.	Does not market a unit for hospitals. Could possibly scale down their current system. They claim efficiency 99.2% EO capture for gas on current models.
	Ceilcote	Many (0)	None; glycol sold for credit	Countercurrent packed column--for industrial applications.	Currently only large-scale application. EO producers on contract sterilizers; not interested in hospital market.

(continued)

TABLE 5-2. (continued)

Control	Company and location	No. of installations (no. in hospitals)	Primary effluent	Operating principles	Comments
	Croll-Reynolds	Many (0)	None, glycol sold for credit.	Countercurrent packed column--for industrial applications.	Not interested in the hospital market.
	Heat Systems Ultrasonics Farmingdale, N.Y.	None for EO control Many for other gases	Ethylene glycol with some sodium sulfate	Venturi scrubber first stage. Then intimate vapor-liquid contact on demisting pad. Acid hydrolysis to glycol, which accumulates. Then neutralize and dump.	Marketed as a "laboratory scrubber" for small-scale $4K price. Limited to scrubbing 1,000 ppm or less in air. Have been working on an EO unit but it is not ready.
Catalytic oxidation	Mine Safety Appliances Evans City, Pa.	5 (5) Not all up yet	$CO_2 + H_2O$	Gas flows through catalyst bed oxidizing EO to CO_2 and H_2O. CFC passes through unreacted. Operating temperature of 300 to 350°F.	Operated since 1986 at Children's Hospital in Philadelphia, Pa. No detectable levels of EO at outlet as measured by GC analysis (0.5-ppm limit).
	DM3 Corporation Santa Ana, Calif.	0 (0)	$CO_2 + H_2O$	Similar to MSA's unit.	DM3 has a marketing agreement with MSA, where they purchase the catalyst from MSA and fabricate the remainder. They provided test data on the MSA unit in Philadelphia. They have not sold any units for hospitals as yet. DM3 also offers a catalytic unit for large

(continued)

TABLE 5-2. (continued)

Control	Company and location	No. of installations (no. in hospitals)	Primary effluent	Operating principles	Comments
					commercial sterilizers wholly manufactured by MSA.
Adsorption	Tigg Corporation Pittsburgh, Pa.	? (0)	Virtually none. Carbon bed must be disposed of. No by-products.	EO trapped as gas flows through activated carbon bed. Can be regenerated for large-scale operations, but not economical for small hospital scale. Designed to be disposable for small scale.	Tigg has had EO control program with "promising results." Have had industrial-scale in mind but say small-scale is possible with their smallest unit of 100 ft^3/min maximum.

5.1 CATALYTIC INCINERATION

The EtO ABATOR™ produced by Mine Safety Appliances Company (MSA) uses an oxidation catalyst to convert EO to carbon dioxide and water (see Figure 5-1). The catalyst has been available commercially for many years and is used for a variety of applications. The reaction with EO takes place catalytically at relatively low temperatures (300°-350°F). Spent sterilizer gas is mixed with a high volume of dilution air to reduce the inlet concentration to 5,000 ppm or less. (This limit is to prevent excessive catalyst bed temperatures from the exotherm of oxidation.) The mixture passes through a filter for dust removal and then is preheated with steam or electricity to the reaction temperature. The gas then enters the catalyst beds, and the EO is oxidized. Before being vented to the atmosphere, part of the stream may be recycled for heat recovery. At the start of the vent cycle, the steam use is minimal since the reaction exotherm provides most of the heat to maintain the operating temperature. As the venting continues and the EO concentration is reduced, the steam use increases to make up the lost heating value. The catalyst unit is illustrated in Figure 5-2.

MSA claims that the EtO ABATOR™ achieves an efficiency of 99.9+%. There are currently six units in operation, three of which are installed in hospitals. The customer list is shown in Table 5-3. This unit can potentially control multiple EO emission sources because the dilution air it requires can be taken from the aeration room air, aeration chamber air, and core room ventilation. Ethylene oxide from these "nonsterilizer" sources may vary from 5-25% of total EO emissions depending on the product being sterilized.

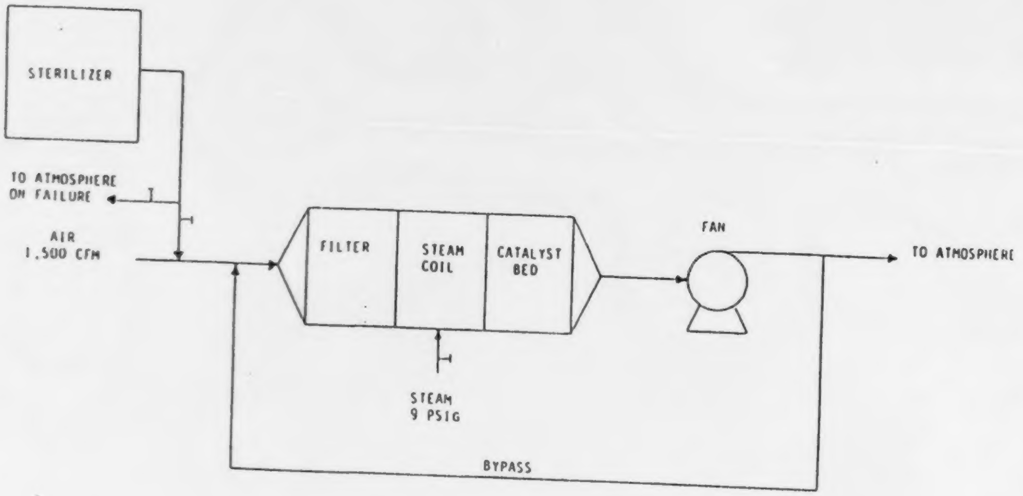

STERILIZER
TO ATMOSPHERE ON FAILURE
AIR 1,500 CFM
FILTER
STEAM COIL
CATALYST BED
STEAM 9 PSIG
FAN
TO ATMOSPHERE
BYPASS

Figure 5-1. Schematic: MSA EtO ABATOR™.

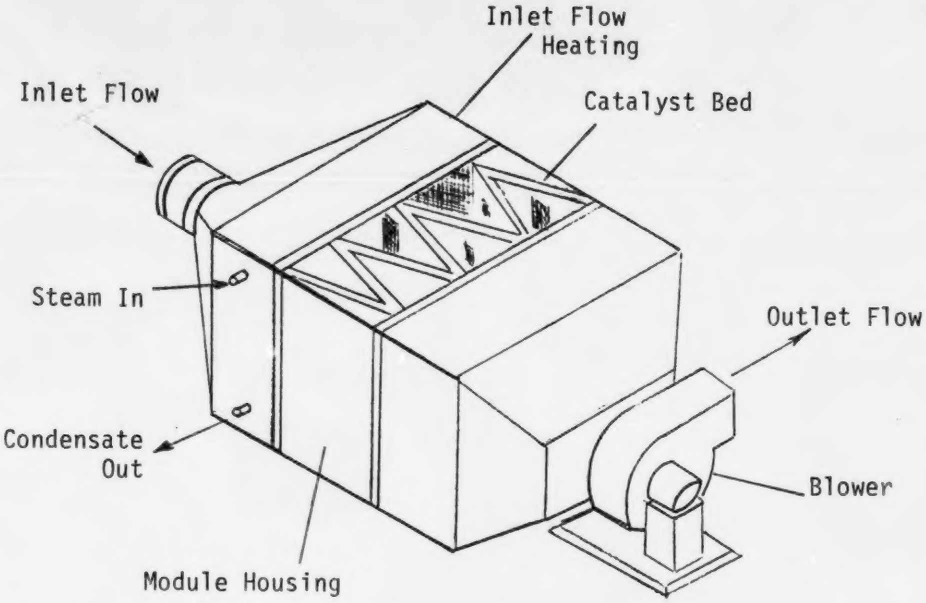

Inlet Flow
Inlet Flow Heating
Catalyst Bed
Steam In
Outlet Flow
Condensate Out
Blower
Module Housing

Figure 5-2. Catalyst unit: The MSA EtO ABATOR™.

TABLE 5-3. PURCHASERS OF MSA EtO ABATOR™ SYSTEMS

The Children's Hospital of Philadelphia
One Children's Center
34th Street and Civic Center Boulevard
Philadelphia, Pennsylvania 19104

Paoli Memorial Hospital
Lancaster Pike
Paoli, Pennsylvania 19301

American Cyanamid Company
Lederle Laboratories Division
Pearl River, New York 10965

Seamless Hospital Products
Division of Dart Industries
9660 Plaza Circle
El Paso, Texas 77927

Seamless Hospital Products
Division of Dart Industries
1909 Northeast 25th Avenue
Ocala, Florida 32670

Logansport Memorial Hospital
Logansport, Indiana 46947

5.2 ACID HYDROLYSIS

Ethylene oxide will hydrolyze in the presence of water, but this reaction is very slow at neutral pH. The half-life of EO in water is approximately 14 days.[1] On either side of neutral, the reaction rate increases, but the reaction under alkaline conditions is a net consumer of alkali, and to maintain the reaction rate, caustic must be added continuously. The reaction under acidic conditions is approximately two orders of magnitude faster than the alkaline reaction and is acid-catalyzed; i.e., it is not a net consumer of acid.[2] Therefore, the pH of the solution remains constant, and no acid addition is necessary. This fact, plus the faster reaction rate, makes acid hydrolysis the choice for hydrolyzing EO.

There are four manufacturers of scrubbing controls specifically for EO emissions. Two of the makers are interested in the hospital sterilizer control market (Chemrox and Damas). The others (Ceilcote and Croll-Reynolds) manufacture systems only for industrial and large contract sterilizer use and do not plan to enter the hospital market. The approaches of Chemrox and Damas are described below.

5.2.1 The Chemrox System

Chemrox, Inc., has installed more than 25 Deoxx™ EO control systems at large contract sterilizers and spice companies. A schematic of the Deoxx™ system is shown in Figure 5-3. The system controls sterilizers having capacities from a few hundred to thousands of cubic feet. These units use a sulfuric acid solution at pH of 1.0 flowing in a countercurrent packed tower to absorb the gaseous EO into the liquid phase where it reacts to form ethylene glycol. The gas is drawn from the sterilizer by a water-ring vacuum pump. The sealant water and 12/88 gas are then separated, and the sealant water, after cooling in a heat exchanger, is returned for reuse as sealant in the pump. This recycle eliminates the discharge of water and prevents drain area EO emissions. The 12/88 gas exits the separator and enters the bottom of the packed tower. At this point, all of the gas from the sterilizer has reached the control device and no fraction has been discharged down the

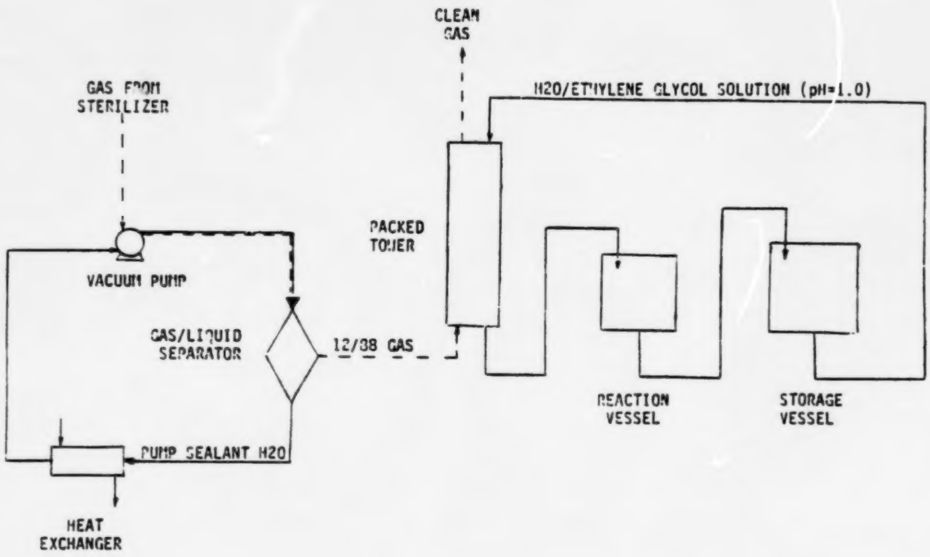

CLEAN GAS
GAS FROM STERILIZER
H2O/ETHYLENE GLYCOL SOLUTION (pH=1.0)
PACKED TOWER
VACUUM PUMP
GAS/LIQUID SEPARATOR
12/88 GAS
REACTION VESSEL
STORAGE VESSEL
PUMP SEALANT H2O
HEAT EXCHANGER

Figure 5-3. The Chemrox Deoxx™ system for scrubbing EO.

drain. The two-step absorption/reaction process begins in the packed tower as the highly soluble EO is absorbed into the water and is hydrolyzed to ethylene glycol. Almost all of the CFC remains in the gas stream because of its relative insolubility in water. Clean, almost EO-free gas exits the top of the column, and the acid/water/glycol solution exits the bottom to a reaction vessel where there is sufficient retention time for the EO to completely hydrolyze. The solution then flows to the storage vessel, which serves as a reservoir for fresh EO-free solution which is recycled to the top of the column (still at pH 1.0). The ethylene glycol slowly builds up in the scrubbing liquor to approximately 40 wt %. At that time, caustic is pumped into the system to neutralize the acid, and the liquor is disposed of or, less often, sold for credit.

Chemrox claims a 99.9% efficiency for their Deoxx™ system when used with pure EO. This figure has been supported by tests.[3] Spice producers and contract sterilization firms have purchased the Deoxx™ system to meet state regulations. In anticipation of regulations on hospitals, Chemrox has been developing a unit for that market. The hospital Deoxx™ is scaled to smaller sterilizers but uses the same process principles as the larger units. Chemrox claims a 99% minimum efficiency for the unit. To achieve this efficiency, the gas flow rate to the unit must be no more than 10 scfm, and Chemrox has a restriction valve in place to ensure this condition. This feature should only affect large hospital sterilizers, where flows normally exceed 10 scfm. The restriction valve will add a few minutes to the evacuation cycle of these sterilizers but should not affect their performance otherwise. The system should fit in a floor space of 4.5 ft x 5 ft x 9 ft.

Chemrox believes that hospital units can operate efficiently until a glycol level of 60 wt % is reached (not 40% as in the former units). The 60% limit should extend the time between fluid changes but is also expected to reduce the cost of distilling the glycol.

5.2.2 The Damas System

Damas Corporation has installed more than 25 EO control units at various sterilizing facilities. The Damas Corporation holds the exclusive license to market an EO-scrubbing technology based on a patent held by Johnson & Johnson. The system is a bubble diffusion scrubber which also uses sulfuric acid to hydrolyze EO to ethylene glycol. A process schematic of the system referred to as the Tri-Phase™ scrubber is shown in Figure 5-4. The 12/88 gas is drawn from the sterilizer by a vacuum pump (Damas, like Chemrox, recommends a recycling vacuum pump system to eliminate drain emissions). The pressure of the mixture is controlled to tight tolerances by a pressure control valve and is sent to the Tri-Phase™ reaction vessel. Inside the vessel is a sulfuric acid solution at a pH of 0.5-1.0. The 12/88 is sparged through a diffuser to create very small bubbles which percolate through the acid solution. The small bubbles maximize mass transfer area, and the EO is absorbed into solution, where it hydrolyzes to ethylene glycol. A demisting pad prevents acid mist from exiting with the clean gas and provides a final polish to the gas stream. The CFC again remains unreacted and is exhausted to the atmosphere. Ethylene glycol builds up in the system to a recommended level of 60%, when it is neutralized and discarded. Damas claims 99.2% efficiency for this system.

Damas currently markets units for flow rates from 100-760 ft^3/min--the range found in industrial sterilizers. Damas has designed a unit for hospital sterilizers which has been tested to be greater than 99% efficient.

5.3 REFERENCES FOR SECTION 5

1. Conway, R. A., et al. 1983. Environmental fate and effects of ethylene oxide. Environmental Science Technology, 17:2, pp. 107-112.

2. Kirk-Othmer. 1980. Encyclopedia of Chemical Technology, 3rd Edition, Vol. 9, p. 436.

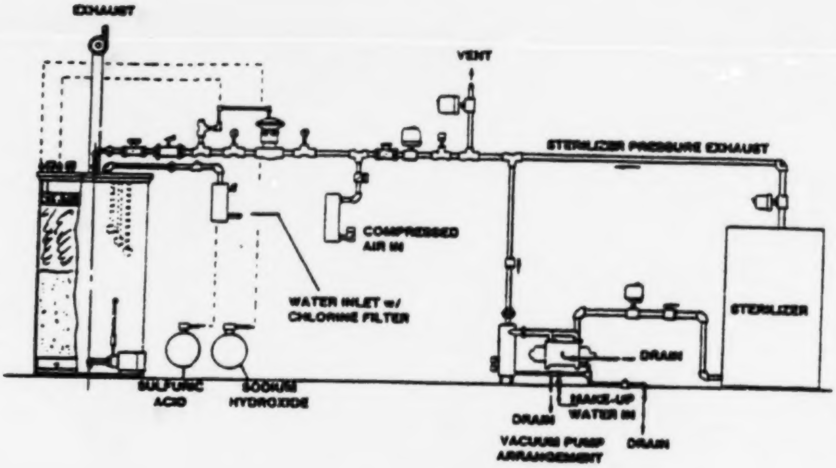

EXHAUST
VENT
STERILIZER PRESSURE EXHAUST
COMPRESSED AIR IN
WATER INLET w/ CHLORINE FILTER
STERILIZER
DRAIN
SULFURIC ACID
SODIUM HYDROXIDE
MAKE-UP WATER IN
DRAIN
VACUUM PUMP ARRANGEMENT
DRAIN

Figure 5-4. The Damas Tri-Phase™ scrubbing system.

Reprint from Damas Product Brochure (1986).

3. Chemrox, Inc. 1985. Performance testing report Deoxx™ ethylene oxide detoxification system.

SECTION 6.0

TESTS OF CATALYTIC OXIDATION SYSTEM

A catalytic oxidation system installed at the Paoli Hospital, Paoli, Pennsylvania, was tested in June 1987. The system had been in operation at the hospital for about 6 months.

The primary goal of the test program was to determine the EO destruction efficiency of the catalyst system. A secondary goal was to measure the extent of chlorofluorocarbon decomposition during the catalytic oxidation process. Two types of experiments were performed; one type involved the treatment of the sterilizer discharge and another type involved adding the sterilizer gas directly to the system.

In all of the experiments, the observed EO destruction efficiency was high, greater than 99%. However, in the sterilizer discharge experiments, only about 10-13% of the EO in the sterilizer actually reached the catalyst system. A major fraction of the EO was absorbed by the water which was used in the once-through vacuum pump. The experiments in which EO was added directly to the system indicated that the system was capable of operating efficiently at concentrations comparable to those developed if the total discharge from the sterilizer were directed into the system. No chlorofluorocarbon decomposition was detected in any of the tests.

A summary of the catalytic oxidation system experiments is presented in Table 6-1.

TABLE 6-1. SUMMARY OF EXPERIMENTS - CATALYTIC OXIDATION SYSTEM[a]

Run no.	Objective	EO concentration in inlet at 500 cfm (ppm)	EO destruction efficiency (%)	Maximum possible CF_2Cl_2 decomposition[b] (%)
1	Sterilizer discharge study	430-0.01	99.40	$< 4 \times 10^{-5}$
2	EO addition study	125-250	99.89	$< 6 \times 10^{-5}$
3	EO addition study	400-600	99.93	NA
4	Sterilizer discharge study (replicate of Run No. 1)	429-0.01	99.16	$< 3 \times 10^{-5}$
5	EO addition study	750-1,100	99.97	$< 4 \times 10^{-6}$
6	EO addition study (replicate of Run No. 5)	750-1,000	99.98	NA
7	Sterilizer discharge study	475-0.27	99.36	$< 2 \times 10^{-5}$

[a] Two kinds of experiments were performed. In the sterilizer discharge studies the sterilizer was allowed to discharge into the catalytic oxidation system. In the EO addition studies, EO (12/88) was introduced from a cylinder into the catalytic oxidation system.

[b] No chloride was detected at a limit of detection of 200 ppb.

6.1 THE CATALYTIC OXIDATION SYSTEM

The catalytic oxidation system uses an oxidation catalyst to convert EO to carbon dioxide and water. The catalyst has been available commercially for many years and is used for a variety of applications. The reaction with EO takes place catalytically at relatively low temperatures (300°-350°F). Spent sterilizer gas is mixed with a high volume of dilution air to reduce the inlet concentration to 5,000 ppm or less. This limit is to prevent excessive catalyst bed temperatures from the exotherm of oxidation. The mixture passes through a filter for dust removal and then is preheated with steam to the reaction temperature. The gas then enters the catalyst beds, and the EO is oxidized. At the start of the sterilizer discharge cycle, the steam use is minimal as the exothermic reaction provides most of the heat to maintain the operating temperature. As the venting continues and the EO concentration is reduced, the steam use increases. When the vent cycle stops, steam use is a maximum.

The Paoli Memorial Hospital operates one EO sterilizer and one EO aerator. The EO sterilizer is a 9-ft^3 sterilizer that is approximately 4 years old. Operation is automatic, but the length of each phase of the sterilization cycle can be adjusted by timers. The current cycle is as follows:

1. The sterilizer is preheated for 30 min.

2. The initial vacuum is drawn to 26 in. of mercury (in. Hg).

3. Steam is injected for 10 min to raise humidity.

4. The 12/88 is introduced and held at 10 psig for 3 hr for complete sterilization.

5. The vacuum pump evacuates chamber to 26 in. Hg vacuum (requires about 5 min).

6. Pulse purges continue for 30 min until cycle ends.

Currently there are 10 pulse purges during which the chamber is repeatedly drawn down and then flooded back to atmospheric pressure. The pulse purges are set on a timer for 30 sec of draw-down, followed by 30 sec of flooding.

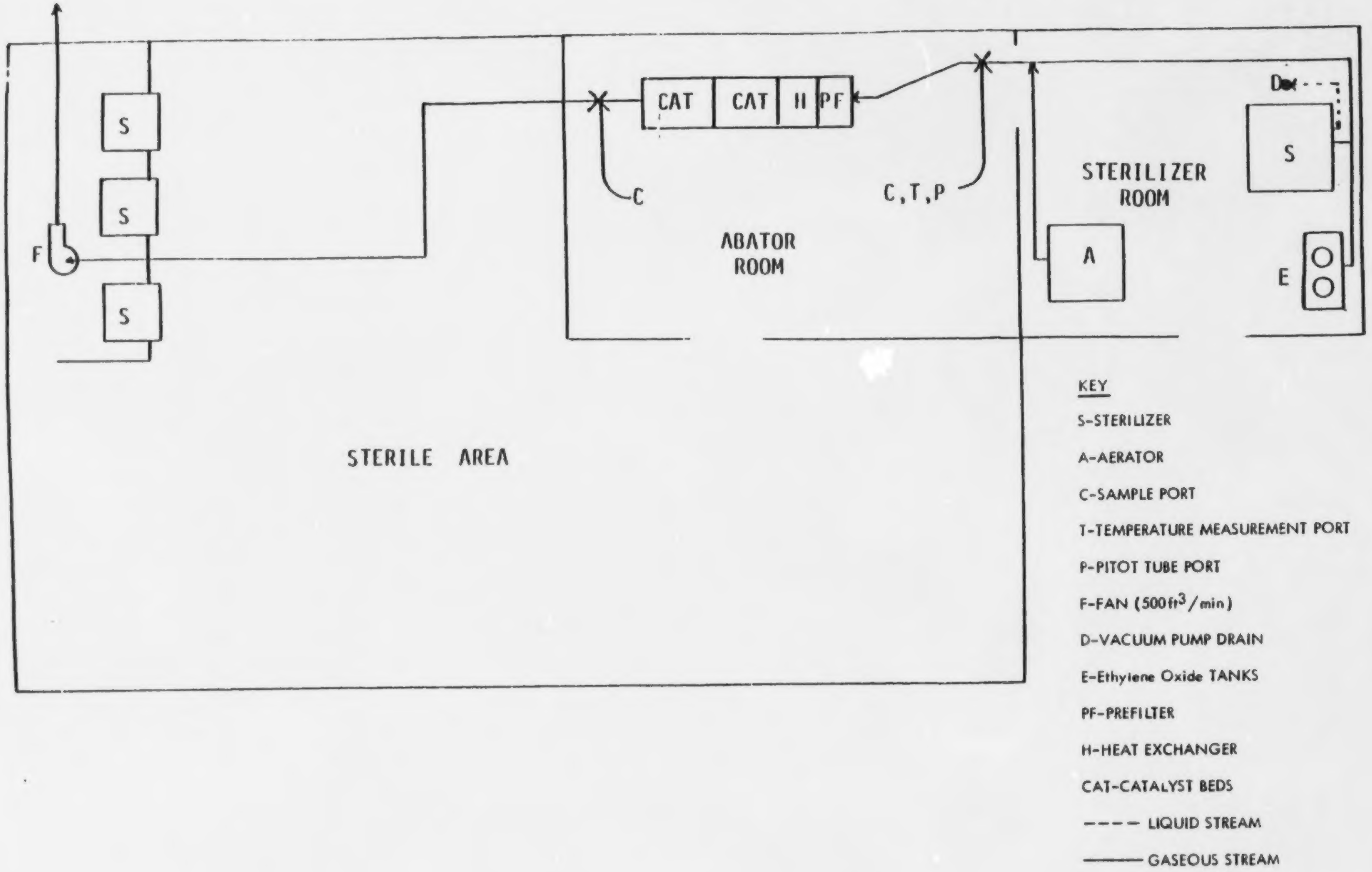
For testing purposes, the entire sterilization cycle was shortened to 30 min by eliminating preheating and steam injection, reducing exposure time from 3 hr to 15 min, and eliminating the pulse purges.

The hospital usually starts the sterilization cycle at about 4 p.m. and removes the sterilized items at approximately 8 p.m. They are immediately placed in the aerator, remain there for 12 hr, and are then removed.

Figure 6-1 is a diagram showing the site layout. The sterilizer, aerator, and EO tanks are located in one room. These devices are all ducted to a common galvanized steel duct (10 x 16 in.) in the ceiling. The duct passes through a wall into the next room (approximately 8 x 15 ft) where the catalytic oxidation system is located. The duct leaves the oxidation system and passes through the next two rooms before exiting out a louvered vent in the exterior wall. Testing was only possible in the room where the oxidation system is located because of space limitations and sterility requirements. While in the area of the sterilizer, test personnel were required to wear sterile gowns, caps, and shoe covers.

Sampling ports were installed at the inlet to and outlet of the oxidation system. Direct EO addition experiments were performed by adding 12/88 directly to the duct at the hood over the EO tanks.

The vacuum pump drain is in the floor next to the sterilizer. The drain is not "hard piped," and high levels of EO may be present in the vicinity of the drain when the vacuum pump is running. The design flow rate of the pump is 2.6 gal/min.


S
S
F
S
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C,T,P
ABATOR ROOM
STERILIZER ROOM
D
S
A
E
STERILE AREA
KEY
S-STERILIZER
A-AERATOR
C-SAMPLE PORT
T-TEMPERATURE MEASUREMENT PORT
P-PITOT TUBE PORT
F-FAN (500ft3/min)
D-VACUUM PUMP DRAIN
E-Ethylene Oxide TANKS
PF-PREFILTER
H-HEAT EXCHANGER
CAT-CATALYST BEDS
---- LIQUID STREAM
—— GASEOUS STREAM

Figure 6-1. Site plan for the Paoli Memorial Hospital sterilization section.

The catalytic oxidation system consists of a prefilter section and a steam heater section followed by two catalyst beds. The heater uses 50 psi steam to heat the incoming air to approximately 300°F before it enters the catalyst beds. The control panel for the system has temperature indicators for both stages of the catalyst beds. Also, pressure gauges indicate the differential pressure across the prefilter and catalyst beds. The system also has a low-flow alarm that sounds when the differential pressure drops below a set point. This protects the unit from overheating in the event of fan failure.

6.2 DESCRIPTION OF STERILIZER DISCHARGE EXPERIMENTS

A diagram of the sampling and analysis system is shown in Figure 6-2. The primary sampling points were located on either side of the catalyst at points labeled 1 and 2. The sample streams were drawn from the ducts through polytetrafluoroethylene tubing.

In order to establish the shape of the concentration versus time curve, it was necessary to sample very rapidly, about every 40 sec. The response time of the GC, which is about 3.0 min, did not allow all of the samples to be taken and analyzed immediately. Therefore, samples were taken at each location and analyzed as soon as possible after collection in the order sampled. Glass syringes (10 mL) were used. The sample ports consisted of rubber septums installed in tees located in the sampling lines. Details of the analytical procedures are presented in Appendix C.

In addition, the EO concentration approaching the catalyst bed was monitored continuously using a total hydrocarbon (THC) analyzer equipped with a flame-ionization detector (FID) (see Figure 6-2). This device indicated when the maximum concentration of EO approached the catalyst bed and facilitated the timing of the multiple GC samples taken on both sides of the catalyst. The THC results also provided the general shape of the concentration versus time curves.

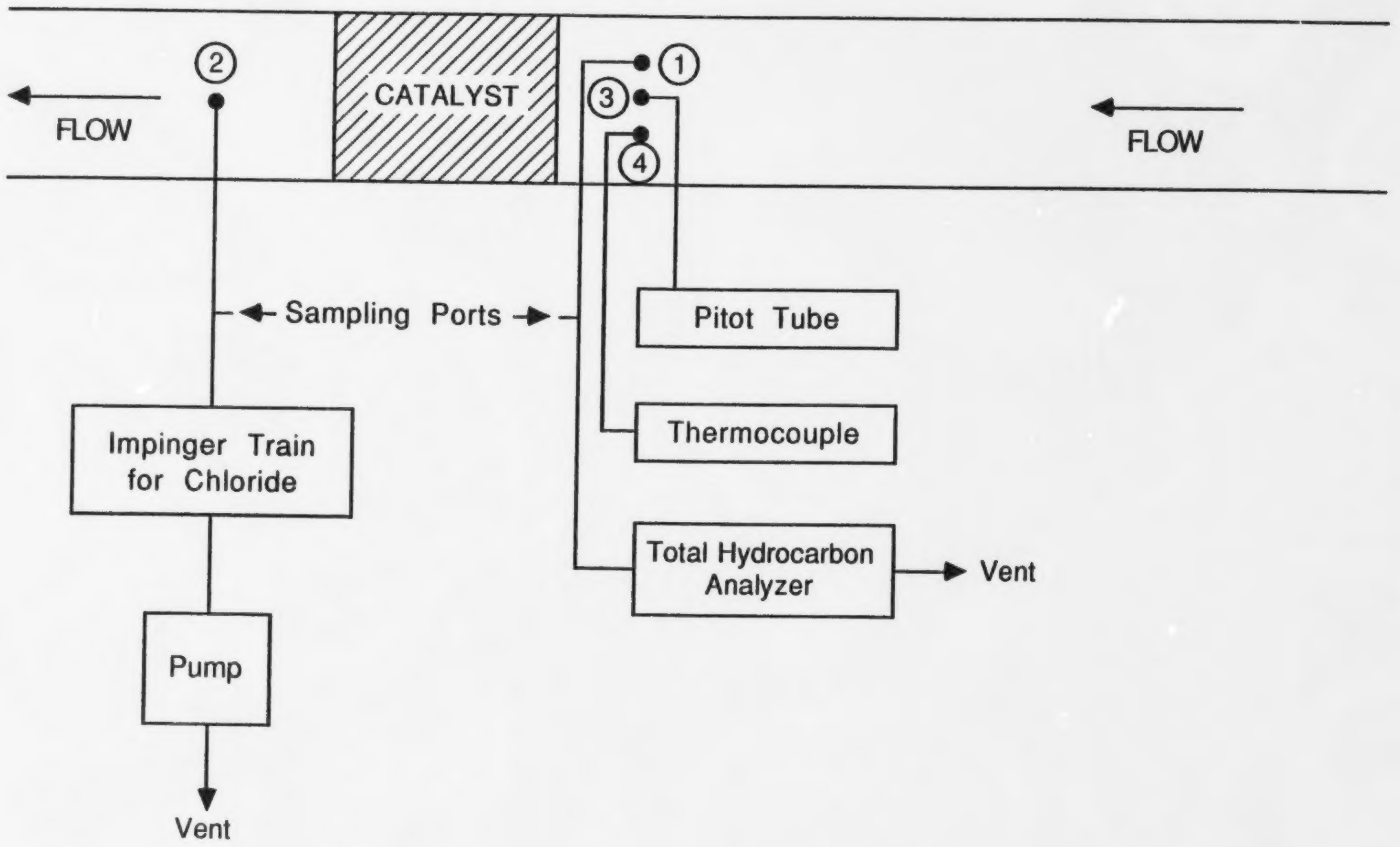

②
CATALYST
①
③
④
FLOW
FLOW
Sampling Ports
Pitot Tube
Thermocouple
Impinger Train for Chloride
Total Hydrocarbon Analyzer
Vent
Pump
Vent

Figure 6-2. Schematic for sampling and analysis of catalytic oxidation system.

The first series of tests involved sampling the inlet and outlet streams of the catalyst system during the evacuation of the sterilizer. In a second series of tests, EO was added to the stream to simulate EO discharges from the sterilizer.

The extent of chlorofluorocarbon decomposition was determined by sampling the exhaust from the catalyst system and analyzing for chloride.

Drain water was sampled during sterilizer discharge and analyzed for EO. Attempts were made to determine the relative amounts of EO discharged from the sterilizer in both the air and water discharges.

Flow rate measurement was accomplished by employing standard, L-shaped pitot tubes, point 3. Prior to the testing of the catalyst system, the pitot tube was used to measure velocities along a traverse of the rectangular duct; velocity determinations were made at four points across the width of the duct. Although the flow volume from the sterilizer decreases during evacuation, the flow at the test point does not change significantly. Thus, the pitot tube-measured velocities are not significantly affected by this change in flow volume. An average flow rate was calculated based on these measurements. During the tests of the catalyst system, the pitot tube was placed at the center of the duct and velocity determinations were made at this point and correlated to the average flow rates. Temperature was measured by installing a thermocouple at point 4 (Figure 6-2).

From the measurements of EO concentration, temperature and flow rate, the EO destruction efficiency (E) was calculated based on the total amount of EO in the exhaust and the total amount of EO in the input stream. The EO destruction efficiency was calculated based upon the total mass of EO which entered the catalyst system and the total mass of EO which left the system:

$$E = \frac{\text{(Mass of EO) in} - \text{(Mass of EO) out}}{\text{(Mass of EO) in}} \times 100$$

The mass of EO entering the system was determined from plots of EO concentration versus time, and flow rate, measured during the 10- to 15-min period when the exhaust gas from the sterilizer passed through the catalyst system. From these plots the total amount of EO entering the system was calculated.

6.3 RESULTS OF STERILIZER DISCHARGE EXPERIMENTS

The results of a representative sterilizer discharge experiment are shown in Figure 6-3, 6-4, and 6-5. Figure 6-3 shows the rapid buildup and decrease of the concentration observed at the inlet during the first sterilizer discharge. Very little EO was observed during the second sterilizer discharge because the sterilizer was very throughly evacuated during the first discharge. The shape of the EO concentration curve was verified using the THC data, which is presented in Figure 6-4.

The observed outlet concentrations are shown in Figure 6-5. Many of these concentrations were near the limit of detection which was 0.1 ppm.

The results of the sterilizer discharge experiments are summarized in Table 6-2. Detailed experimental results are presented in Appendix D and analytical procedures are presented in Appendix C.

The experiments indicated that the catalytic oxidation system operated at high efficiency, greater than 99%. However, as pointed out in the following section (Section 6.4) only about 10-13% of the EO in the sterilizer actually reached the oxidation system. A major fraction of the EO was apparently absorbed by the water which was used in the once-through vacuum pump.

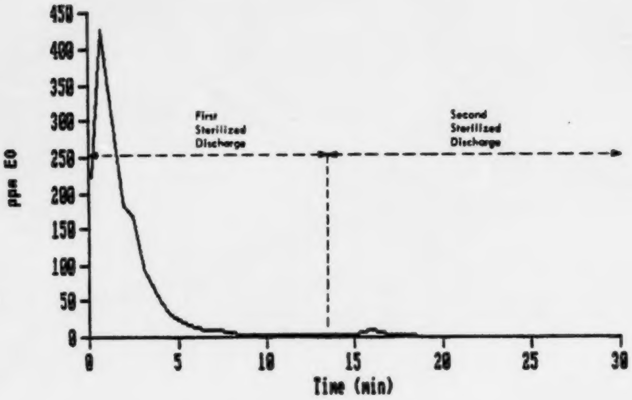


Figure 6-3. Catalytic oxidation system--sterilizer discharge study--inlet concentrations (run 4).

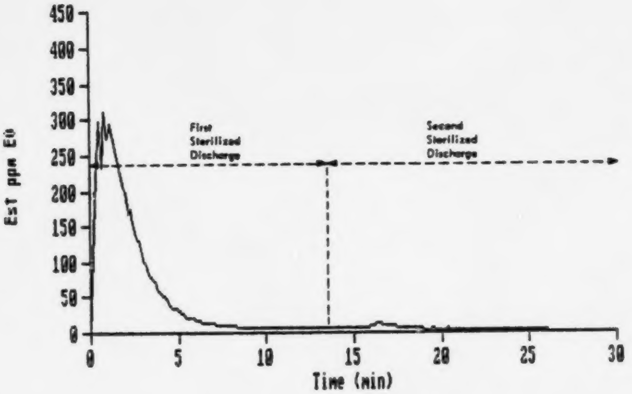


Figure 6-4. Catalytic oxidation system--sterilizer discharge study--inlet concentrations detected by total hydrocarbon analyzer (run 4).

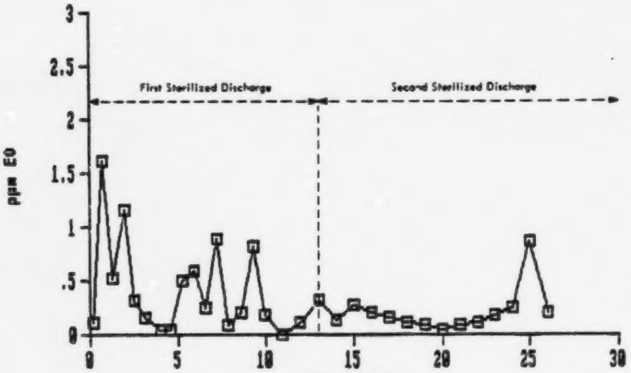


Figure 6-5. Catalytic oxidation system--sterilizer discharge study--outlet concentrations (run 4).

TABLE 6-2. RESULTS OF STERILIZER DISCHARGE STUDIES

Run No.	Total ethylene oxide to inlet (g)[a]	Total ethylene oxide from outlet (g)[a]	EO destruction efficiency
1	20.93	0.125	99.40
4	17.65	0.148	99.16
7	18.89	0.120	99.36

[a] The data from which these calculations were made are presented in Appendix D.

6.4 DETERMINATION OF ETHYLENE OXIDE IN VACUUM PUMP DRAIN WATER

Samples of water were collected at the sterilizer drain during the discharge of the sterilant gas. Since the concentration of EO was expected to vary widely with time, samples were taken frequently (about one per minute) during the first 5 min of the sterilizer discharge, and less frequently during the remainder of the sterilizer discharge. The water samples were placed in glass vials having lids equipped with polytetrafluoroethane seals. These samples were analyzed on-site by GC. Analytical procedures are presented in Appendix C.

The results of one of these experiments (run 1) are presented in Figure 6-6. The EO concentrations in the water were very much higher than expected (about 15,000 ppm maximum). The overall plot very closely paralleled the shape of the curve of the EO at the inlet of the catalytic oxidation system (see Figure 6-3).

These experiments are summarized in Table 6-3. Experimental details are presented in Appendix D and the analytical procedures are presented in Appendix C.

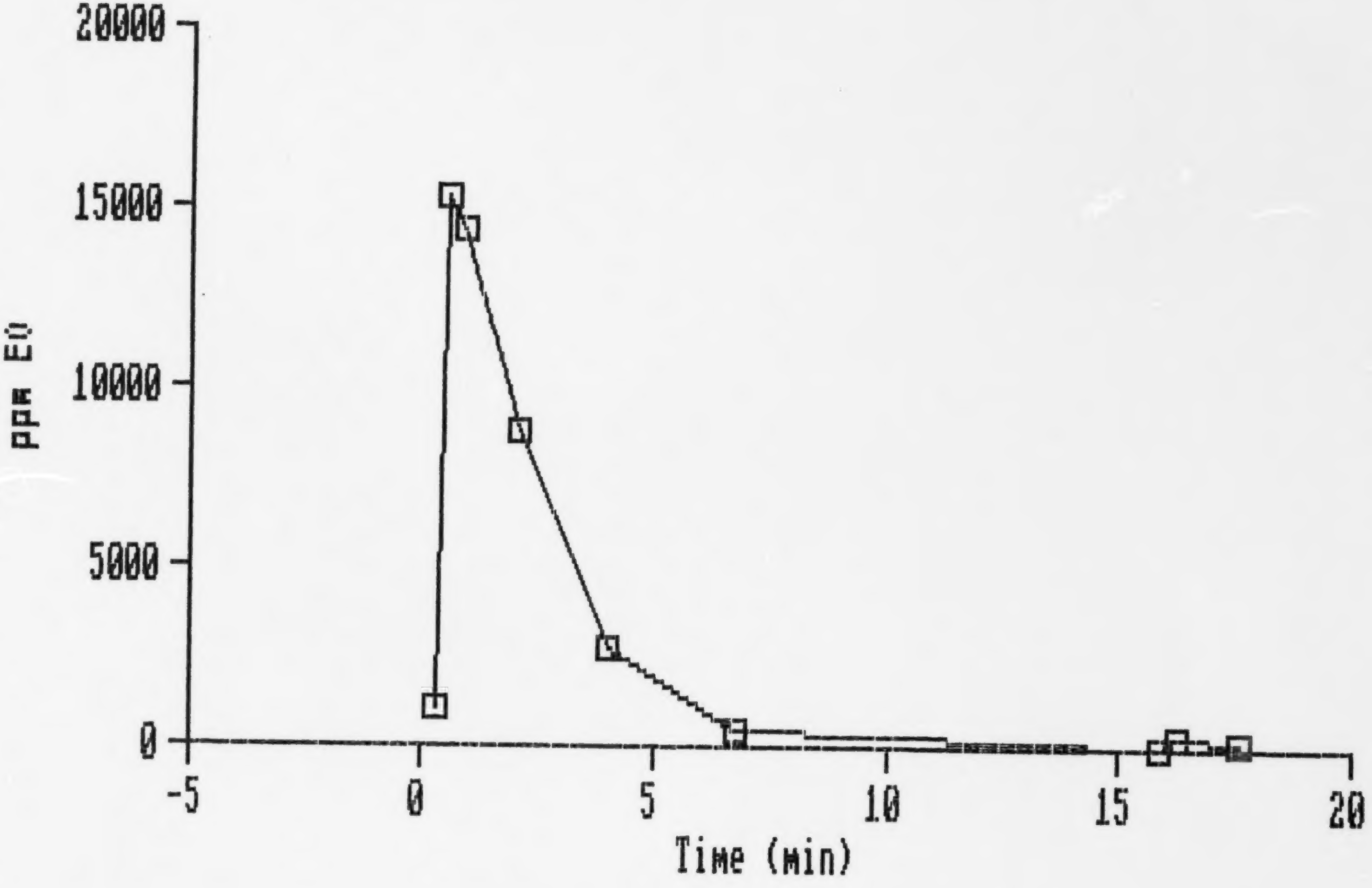


Figure 6-6. Catalytic oxidation system--sterilizer discharge studies. Concentrations of ethylene oxide in vacuum pump water discharge (run 1).

TABLE 6-3. ESTIMATED MATERIAL BALANCE (STERILIZER DISCHARGE STUDIES)

Run no.	Ethylene oxide in sterilizer (g)	Ethylene oxide to inlet (g)	Ethylene oxide to inlet (%)[a]	Ethylene oxide in water discharge (g)	Ethylene oxide in water discharge (%)[b]
1	163	20.93	12.8	127	78
4	165	17.65	10.7	101	61
7	168	18.89	11.2	-[c]	-[c]

[a] The data from which these calculations were made are presented in Appendix D.

[b] The percentages are based on the amount of ethylene oxide in the sterilizer.

[c] No water samples were taken in run 7.

The data in Table 6-3 indicate that, during the sterilizer discharge, only 10.7-12.6% of the EO in the sterilizer reached the oxidation system. An unexpectedly large proportion of the EO (61-78%) was discharged to the sewer in the water from the vacuum pump. Although during these tests the control unit did not process the total sterilizer EO charge, the determination of control efficiency was not affected. Later tests were conducted where EO equivalents to the total sterilizer charge were discharged through the control unit.

During these experiments, an examination of the sterilizer revealed that a gas-liquid separator had been installed in the line conducting water from the vacuum pump to the sewer. An unexpected observation was that the gaseous discharge from this separator, although originally designed to be ducted to the control device, was actually vented outside the hospital, bypassing the control device. It was not feasible to determine how much EO, if any, was discharged through this vent. However, the mass balance accounted for 72-91% of the EO, indicating that only a small fraction could have been vented.

A further unexpected observation was that the water flow rate from the vacuum pump was substantially lower than expected. The design flow rate of the vacuum pump is 2.6 gallons per minute (gpm), and the measured flow rate was approximately 0.9 gpm.

6.5 DETERMINATION OF CATALYST EFFICIENCY BY ADDING ETHYLENE OXIDE TO SYSTEM

Additional experiments were performed in order to supplement the analytical data obtained during sterilizer discharge. EO was added (at a controlled rate) to the system at a point located upstream from the catalyst system. Sufficient EO was added to bring the concentration of the stream to selected levels of EO. Three levels, 125-250 ppm, 400-600 ppm, and 750-1,500 ppm were tested. These concentrations were maintained for 3-5 min, allowing multiple samples to be taken on each side of the catalyst. The feed stock for the EO additions was the sterilizing mixture (12/88).

The experimental procedures were practically identical to those described for the test of the catalyst system during sterilizer discharge (refer to Section 6.2). The EO was added to the system using a calibrated rotameter and the THC analyzer was used as before. As in the other studies, samples were taken on each side of the catalyst at approximately 40-sec intervals. Temperature and flow rate were also determined as in the sterilizer discharge studies.

The results of a representative EO-addition experiment (run 5) are presented in Figures 6-7, 6-8, and 6-9. Figure 6-7 shows the inlet concentrations detected by the GC analyses; Figure 6-8 shows the analogous THC data. Figure 6-9 shows the outlet concentrations detected by GC.

The results of this experiment and the other EO-addition experiments are summarized in Table 6-4. All of the experiments indicated high EO destruction efficiencies, 99.8% or better.

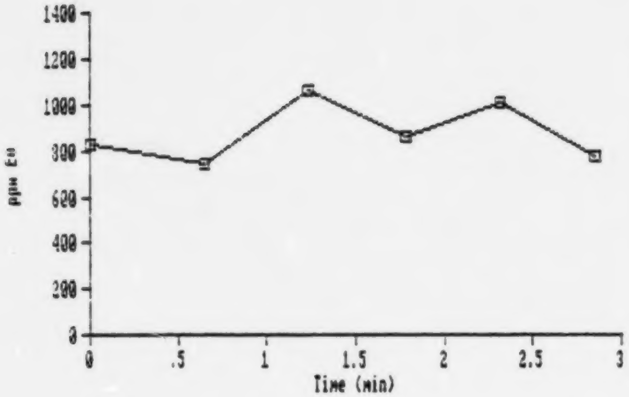


Figure 6-7. Catalytic oxidation system--ethylene oxide addition studies--inlet concentrations (run 5).

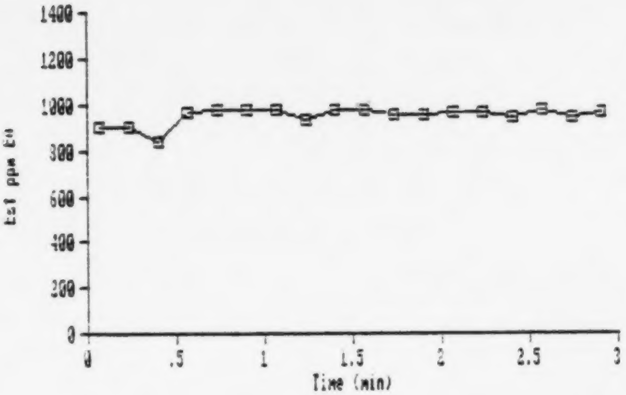


Figure 6-8. Catalytic oxidation system--ethylene oxide addition studies--inlet concentrations detected by total hydrocarbon analyzer (run 5).

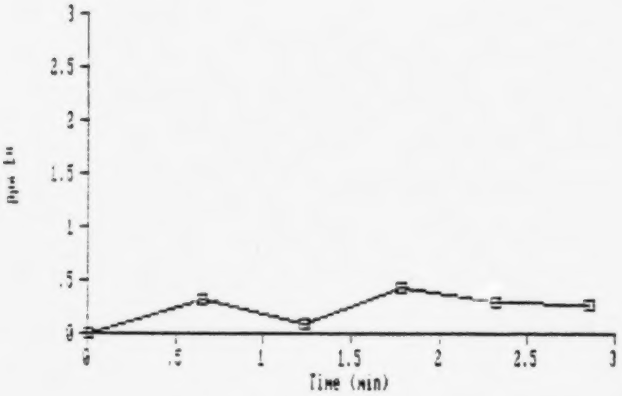


Figure 6-9. Catalytic oxidation system--ethylene oxide addition studies--outlet concentrations (run 5).

TABLE 6-4. ETHYLENE OXIDE DESTRUCTION EFFICIENCY DETERMINED BY ADDING ETHYLENE OXIDE (EO) TO SYSTEM

Run no.	EO concentration at inlet (ppm)	Total EO to inlet (g)[a]	Total EO from outlet (g)[a]	EO destruction efficiency (%)
2	125-250	12.43	0.014	99.89
3	400-600	40.53	0.039	99.93
5	750-1,100	48.67	0.014	99.97
6	750-1,500	52.24	0.012	99.98

[a] The data from which these calculations were made are presented in Appendix E.

An important significance of these experiments is that they demonstrate that the catalytic oxidation system was capable of operating very efficiently at concentrations of sterilizer gases comparable to those developed if the total discharge from the sterilizer were directed into the system. (The results of the sterilizer discharge studies (Table 6-3) showed that less than 13% of the sterilizer discharge had reached the catalytic oxidation system.)

Additional details concerning these experiments are presented in Appendix E and the analytical procedures are described in Appendix C.

6.6 TESTS FOR CHLOROFLUOROCARBON DECOMPOSITION

The EO used for sterilization contains 88% by volume of the chlorofluorocarbon (CFC) dichlorodifluoromethane (CF_2Cl_2). The possible thermal decomposition of the CFC at excessively high catalyst temperatures could result in the emission of several highly toxic and highly corrosive materials such as hydrogen chloride, hydrogen fluoride, phosgene ($COCl_2$), and chlorine. The extent of this decomposition was tested by analyzing samples of the catalyst exhaust stream for chloride during periods when the catalyst temperature was high. Maximum catalyst temperatures occur immediately after the highest concentrations of EO pass through the catalyst.

The sample stream was the same as that used to measure EO on the exhaust side of the catalyst (see point 2, Figure 6-2). The stream was passed through an impinger containing 0.1 N sodium carbonate. The alkaline samples were analyzed for chloride using ion chromatography (analytical procedures are presented in Appendix C).

The results of the chlorofluorocarbon decomposition tests are presented in Table 6-5. No chloride was detected in any of the samples; the detection limit was 200 ppb. Apparently no decomposition of the CF_2Cl_2 occurred. Additional experimental details are presented in Appendix F.

TABLE 6-5. RESULTS OF CHLOROFLUOROCARBON DECOMPOSITION TESTS

Run no.	Maximum catalyst temperature (°F)	Total weight of CF2Cl2 through system (kg)	Maximum possible CF_2Cl_2 decomposition (μg)	Maximum possible CF_2Cl_2 decomposition (%)[a]
1	283	1.20	< 518	$< 4 \times 10^{-5}$
2	287	0.104	< 67	$< 6 \times 10^{-5}$
4	299	1.21	< 408	$< 3 \times 10^{-5}$
5	311	0.41	< 16	$< 4 \times 10^{-6}$
7	282	1.24	< 262	$< 2 \times 10^{-5}$

[a] No chloride was detected at a limit of detection of 200 ppb. Apparently no decomposition of the CF_2Cl_2 occurred. Additional experimental details are presented in Appendix F.

SECTION 7.0

COST ESTIMATES FOR CATALYTIC OXIDATION SYSTEM

Capital and operating costs for the catalytic oxidation system have been estimated from data provided by the hospitals where they have been installed, other hospital contacts, the control device vendors, and observations made during site visits to the installation. A summary of the projected costs is presented in Table 7-1.

Because there are only two hospital installations available for study (Children's Hospital of Philadelphia and Paoli Memorial Hospital, Paoli, PA), and the technology in question is very new, the cost estimates presented here remain approximate and may not accurately reflect the costs for future installations. A discussion of both capital and operating costs is presented below.

7.1 CAPITAL COSTS

Capital cost estimates for this control device vary widely from source to source. The equipment costs estimate provided for the unit at the Children's Hospital of Philadelphia (a 1,500-cfm unit with an economizer) is $25,000. The estimate provided by Paoli Memorial Hospital for their unit (a 500-cfm unit without an economizer) is $40,000. Installation costs depend entirely on the specific site. Thus, based on these installations, absolute flow rate is not necessarily indicative of total system costs. Installation cost factors include: the design airflow of the unit's fan (determines duct size), the availability of space near the sterilizer, proximity of the unit to an outside wall (determines the length of duct work required), the number of sterilizers

TABLE 7-1. COST ESTIMATES FOR THE CATALYTIC OXIDATION SYSTEM

Capital Costs	
Equipment Cost:	$25,000 to $40,000
Installation Costs:	$ 5,000 to $10,000
Total Equipment Cost:	$30,000 to $50,000
Annual Operating Costs	
Steam for Preheater:	$3,900 to $12,300
Electricity for Fan:	$ 580 to $ 1,740
Annualized Catalyst Replacement:	$ 800 to $ 1,330
Annualized Prefilter Replacement:	$ 25
Maintenance Labor (12 hr @ $35/hr):	$ 420
Estimated Total Annual Operating Cost:	$5,725 to $15,815

and aerators connected to the system, the materials of construction, and Table 7-1 other factors. The costs of installation presented in Table 7-1 are based on estimates provided by the hospitals that have installed the unit and are approximately 20-25% of the purchased equipment cost.

7.2 OPERATING COSTS

An analysis of the catalytic oxidation unit's operating costs has identified four major cost items: (1) the cost of steam to preheat the incoming air, (2) the cost of electricity to run the fan, (3) the cost of catalyst and prefilter replacement, and (4) the labor cost of maintenance. A summary of operating costs is presented in Table 7-1, and a more detailed discussion of each follows.

7.2.1 Cost of Steam

In both hospital installations the catalytic oxidation unit requires steam supplied to a heat exchanger to preheat the incoming air to proper temperatures for catalysis. The recommended operating temperature is 275° to 300°F (135°-150°C). The units in both hospitals are kept at this operating temperature 24 hr/day, 360 days/year. The cost to the hospital for steam generation varies depending on the type and size of steam generating process, and the cost of fuel. The cost to produce steam at the Children's Hospital of Philadelphia is approximately $9/1,000 lb of steam.[1] Another estimate from Rex Hospital in Raleigh, North Carolina was $5.20/1,000 lb.[2] The smaller Paoli Hospital unit (500 ft^3/min) requires approximately 1.5 lb of steam to heat 500 ft^3 of air every minute of operation.[3] For the Children's Hospital unit (1,500 ft^3/min), which must heat three times the amount of air, the steam usage is greater. However, the Children's Hospital unit also has had an economizer installed as an option. The economizer is a heat exchanger that uses the waste heat from the outlet gases to preheat the incoming air. This reduces steam usage by an estimated 40%.[3] Thus, the Children's Hospital unit uses approximately 2.6 lb of steam per minute to heat the incoming air. These steam usage figures were multiplied by the range of steam costs ($5.20 and $9/1,000 lb of steam) to determine the range of expected steam costs for both units presented in Table 7-1.

7.2.2 Cost of Fan Power

The cost of moving 500-1,500 ft^3 of air per minute was calculated using the cost equations contained in Reference 4. The range presented in Table 7-1 represents the Paoli Hospital unit and the Children's Hospital unit, respectively.

7.2.3 Annualized Catalyst and Prefilter Replacement Costs

The cost of catalyst for the catalytic oxidation unit is approximately $2,000/cell, installed.[5] Both hospital units have two catalyst cells. Thus, the replacement cost is estimated to be $4,000/unit. Neither hospital has had to replace the catalyst beds as of yet with more than a year of operating time in the case of the Children's Hospital unit. The estimated catalyst life, provided normal operating parameters are maintained, is from 3-5 years.[5] Therefore, range of costs in Table 7-1 were calculated by annualizing the catalyst replacement cost over the expected 3- to 5-year catalyst life.

In addition, the units prefilter will need replacement every 3 years at a cost of $75.[5] This adds approximately $25 to the annual operating costs of the unit.

7.2.4 Maintenance Labor Costs

According to hospital sources at hospitals where the catalytic oxidation system has been installed, the unit has required virtually no time for maintenance.[1,6] However, as the units require catalyst or prefilter replacements or normal fan maintenance, a nominal maintenance estimate of 1 hr per operating month was applied to the annual operating cost. The net cost of 12 hr of labor at $35/hr is reflected in Table 7-1.

7.3 REFERENCES FOR SECTION 7.0

1. Telecon. B. Nicholson, MRI, with R. Ewing, Children's Hospital of Philadelphia. August 5, 1987. Capital costs and energy requirements of the catalytic oxidation system.

2. Telecon. B. Nicholson, MRI, with W. Tice, Rex Hospital, Raleigh, North Carolina. August 10, 1987. Cost of steam at Rex Hospital.

3. Memorandum from B. Nicholson to Ethylene Oxide Demonstration Project Files. August 13, 1987. Calculations for cost estimation.

4. Neveril, R. B., GARD, Inc. Capital and Operating Costs of Selected Air Pollution Control Systems. Prepared for U.S. Environmental Protection

Agency, Research Triangle Park, North Carolina. Publication No. EPA-450/5-80-002 (NTIS PB80-157282). December 1978.

5. Telecon. B. Nicholson, MRI, with P. Coward, Coward-Eastman, Inc., Gloucester, New Jersey. August 11, 1987. Costs and replacement schedules for the catalytic oxidation system.

6. Telecon. B. Nicholson, MRI, with B. Fahey, Paoli Memorial Hospital, Paoli, Pennsylvania. August 10, 1987. Capital and operating cost of the catalytic oxidation system.

SECTION 8.0

TESTS OF ACID-HYDROLYSIS SYSTEM

A full-scale acid-hydrolysis system was tested under laboratory conditions which closely simulated a system which could be used for hospital sterilizers. The primary goal was to determine the EO destruction efficiency of the system. Experiments were performed in which a sterilizer discharge was conducted through the system, and in other experiments, the sterilizer gas (12/88) was added directly to the system. In both types of tests, the observed EO destruction efficiency was very high, greater than 99.99% in all of the experiments. When the sterilizer was discharged to the system, the data indicate that substantial quantities of EO were being absorbed by the sealant liquid of the vacuum pump and subsequently released when the pump was purged with air on the second sterilizer evacuation. A summary of the acid-hydrolysis system experiments is presented in Table 8-1.

8.1 THE ACID-HYDROLYSIS SYSTEM

A schematic of the acid-hydrolysis system is shown in Figure 8-1. The system uses sulfuric acid solution at pH 1.0 to absorb gaseous EO into the liquid phase, where it reacts to form ethylene glycol (EG). The reaction is acid-catalyzed, so there is no net loss of acid as the EO is reacted to form EG. The gas is drawn from the sterilizer using a two-stage liquid-ring vacuum pump which uses EG as the sealant liquid. The sealant liquid and 12/88 gas are then separated, and the sealant liquid is conducted to a reservoir and returned for reuse as sealant in the pump. This recycle eliminates the discharge of liquid and prevents drain area EO emissions. The 12/88 gas exits

TABLE 8-1. SUMMARY OF EXPERIMENTS - ACID HYDROLYSIS SYSTEM[a]

Run no.	Objective	EO concentrations at inlet (%)[b]	Flow rate (scfm)[c]	Observed EO destruction efficiency (%)
1	EO addition study	17.55-24.37	2.5	> 99.999
2	EO addition study	19.22-22.67	2.5	> 99.999
3	EO addition study	21.05-24.38	2.5	> 99.999
4	Sterilizer discharge study	3.40-8.38	0.31-1.52	> 99.998
5	Sterilizer discharge study	1.92-10.92	0.34-1.56	> 99.998
6	Sterilizer discharge study	4.21-13.95	0.11-1.56	> 99.995
7	Sterilizer discharge study	5.16-10.66	0.33-1.41	> 99.998

[a] Two kinds of experiments were performed. In the sterilizer discharge studies the sterilizer was allowed to discharge into the acid-hydrolysis system. In the EO addition studies, EO (12/88) was introduced from a cylinder into the acid hydrolysis system.

[b] In the EO addition studies, the EO concentrations were selected to simulate typical sterilizer discharge concentrations. These concentrations were not realized in the sterilizer discharge studies because of EO absorption by the fluid in the vacuum pump (see text).

[c] In the EO addition studies, the flow rate was selected based upon the flow rate capacity of the acid hydrolysis system. In the sterilizer discharge studies, the flow rates varied because the sterilizer was being gradually evacuated.

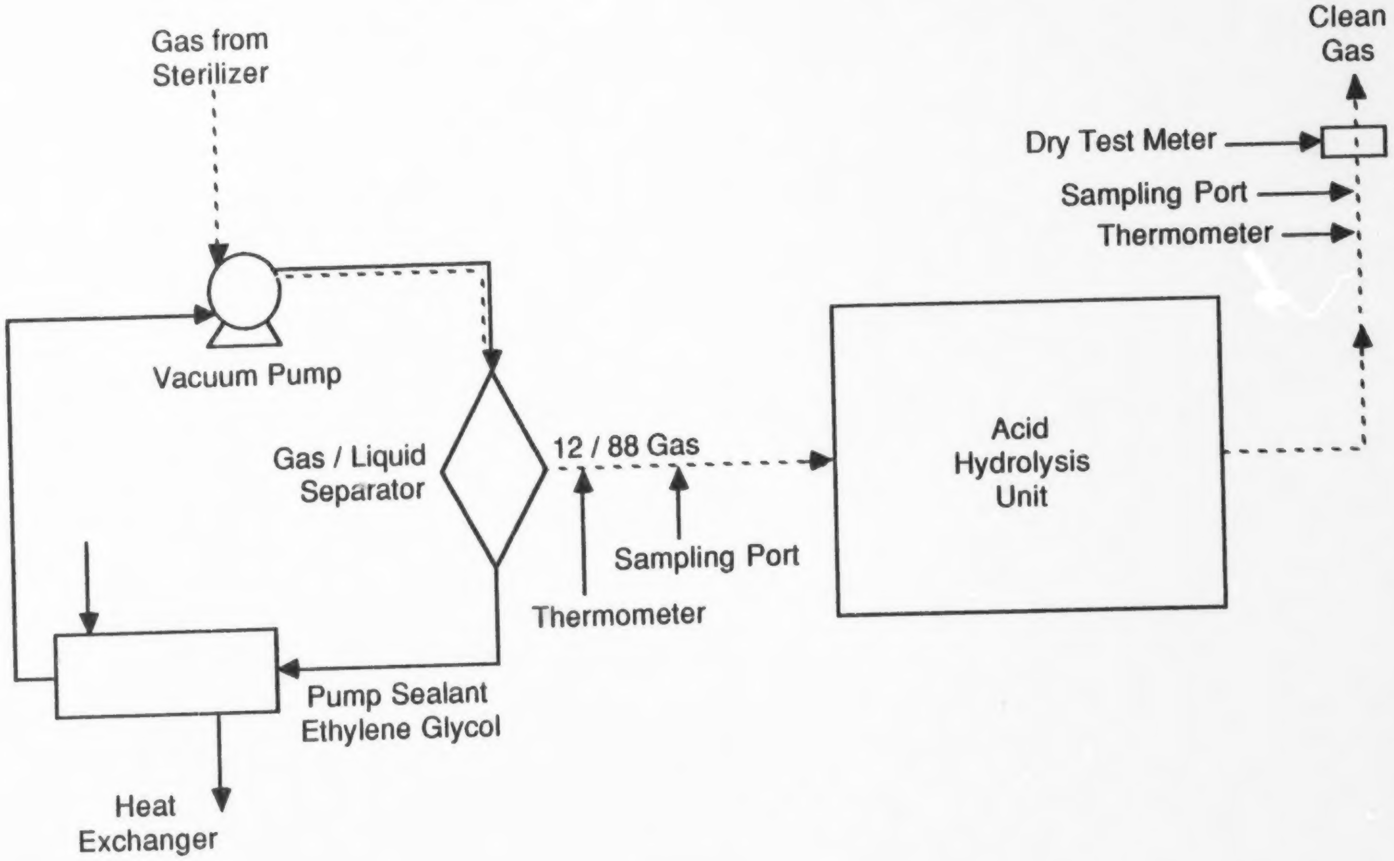

Gas from Sterilizer
Vacuum Pump
Gas / Liquid Separator
12 / 88 Gas
Thermometer
Sampling Port
Acid Hydrolysis Unit
Dry Test Meter
Sampling Port
Thermometer
Clean Gas
Pump Sealant Ethylene Glycol
Heat Exchanger

Figure 8-1. Schematic of acid-hydrolysis system showing sampling and analysis locations.

the pump and is conducted to the bottom of a packed tower. All of the gas from the sterilizer is conducted into the control device, and no fraction is discharged down the drain. The two-step absorption/reaction process begins in the packed tower, as the highly soluble EO is absorbed into the water and is hydrolyzed to EG. Almost all of the chlorofluorocarbon (CFC) remains in the gas stream because of its relative insolubility in water. Clean, almost EO-free gas exits the top of the column, and the acid/water/glycol solution exits the bottom to a reaction/storage vessel where there is sufficient retention time for the EO to completely hydrolyze. Fresh, EO-free solution is recycled to the top of column (still at pH = 1.0). The ethylene glycol slowly builds up in the liquor to approximately 60 wt %.

For maximum efficiency, the gas flow rate to the system is limited to a selected maximum flow, in this case, 2.5 scfm.

8.2 DESCRIPTION OF THE EXPERIMENTS

The objectives of the experiments were to determine flow rates and EO concentrations immediately upstream and downstream of the system in order to calculate the EO destruction efficiency of the system.

Seven experimental measurements of the effectiveness of the system were conducted. Four experiments involved system operation during sterilizer discharge, and three were done in which 12/88 was added to the system. A schematic of the sampling and analysis system is shown in Figure 8-1. The primary sampling points were located on either side of the system. The sample streams were drawn through polytetrafluoroethylene tubing to sample ports, which consisted of rubber septums located in the lines.

Determination of the total EO mass flow required simultaneous measurement of EO concentration and total gas stream flow rate. EO concentrations were measured by pulling syringe samples from the stream and analyzing them on site using a gas chromatograph (GC).

In all of the experiments, it was necessary to sample very rapidly, as often as every 40 sec. The response time of the GC, which was about 3.0 min, did not allow all of the samples to be taken and analyzed immediately. Therefore, samples were taken at each location and analyzed as soon as possible after collection in the order sampled. Glass syringes were used.

The analysts took samples from each side of the system, beginning when the sterilizer gas reached the system. Sampling stopped when the gas flow stopped.

The flow rate through the scrubber was measured using a calibrated dry test meter (Figure 8-1). The flow rate at the inlet was calculated based on the flow rate at the outlet, subtracting the amount of EO removed. The dry test meter was read at the same time that the samples were taken.

From the measurements of EO concentration, temperature, and flow rate, the EO destruction efficiency was calculated based on the total amount of EO which entered the system and the total amount which left the system.

8.3 RESULTS OF STERILIZER DISCHARGE EXPERIMENTS

The results of the sterilizer discharge experiments are summarized in Table 8-2, and additional details are presented in Appendix G. Four runs were made, and the results of a typical run (run 4) are presented in Figures 8-2 and 8-3. Figure 8-2 shows the EO concentrations detected in the inlet samples. Figure 8-3 shows the flow rate from the sterilizer to the inlet during the two evacuation cycles. A combination of the data in Figures 8-2 and 8-3 yields the total amount of EO which went into the system (see Table 8-2). No EO was detected in the outlet (except for an anomaly discussed below) where the detection limit was 1 ppm. As shown in Table 8-1, the observed EO destruction efficiency was greater than 99.99% in all experiments.

TABLE 8-2. SUMMARY OF STERILIZER DISCHARGE EXPERIMENTS[a]

Run no.	EO concentrations at inlet (%)	Flow rate (scfm)	EO into system (g)	EO emissions from system		Observed EO destruction efficiency (%)
				ppm	mg	
4	3.40-8.38	0.31-1.52	38.8	< 1	< 0.8	> 99.998
5	1.92-10.92	0.34-1.56	51.3	< 1	< 0.7	> 99.998
6	4.21-13.95	0.11-1.56	86.2	< 1	< 4.4	> 99.995
7	5.16-10.66	0.33-1.41	58.3	< 1	< 0.8	> 99.998

[a] Additional experimental data are presented in Appendix G.

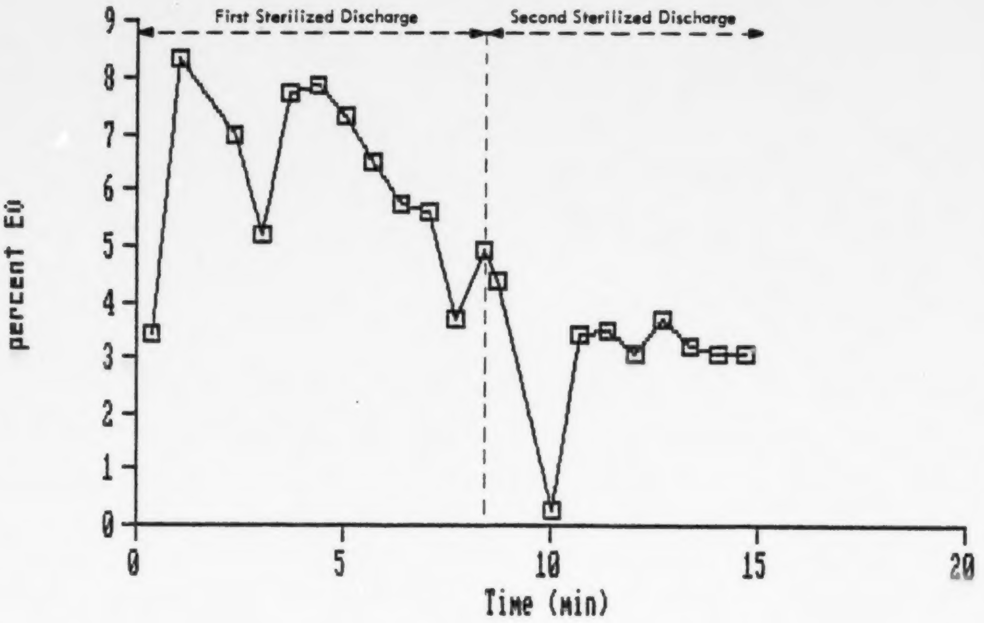


Figure 8-2. Acid hydrolysis system--sterilizer discharge studies--inlet concentration (run 4).

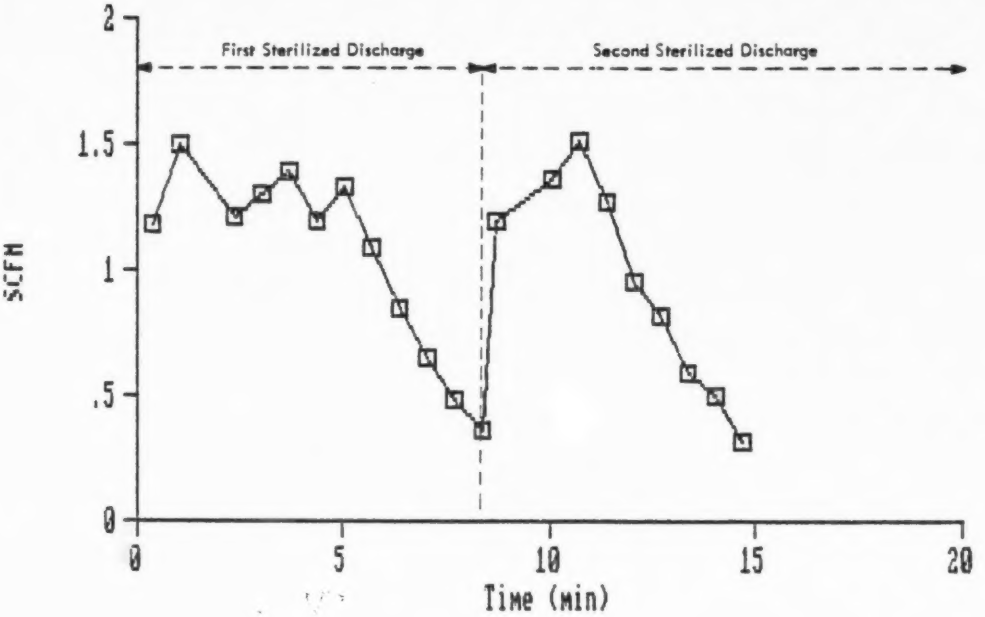


Figure 8-3. Acid hydrolysis system--sterilizer discharge studies--inlet flow rate (run 4).

There were several unexpected observations which indicated that EO was being absorbed by and released from the sealant liquid of the vacuum pump. The pump was a recirculating, liquid-ring vacuum pump which used ethylene glycol (16 gal.) as the sealant liquid.

The first observation was the fact that the EO concentration at the inlet during the first evacuation cycle did not approach the expected concentration of 12/88, which is about 26%. This concentration should have been relatively constant during the sterilizer discharge. In a typical experiment, as shown in Figure 8-3, this concentration varied widely between about 3 and 8.5%. Similar observations were made in all of the sterilizer discharge experiments and indicate that EO was being absorbed by the sealant liquid. The vacuum pump was serving as a scrubber during the first evacuation by mechanically mixing the EO with the sealant liquid.

During the second evacuation, the EO concentration would also be expected to be constant, but less than about 0.1%, because the sterilizer had been thoroughly evacuated during the first evacuation cycle, then returned to atmospheric pressure by allowing air to reenter the sterilizer chamber. As seen in Figure 8-3, the EO concentrations during the second evacuation were unexpectedly high and variable, between 0.24 and 3.7%. Similar observations were made in all of the experiments (see Appendix G) and can best be explained by release of EO from the sealant liquid. During the second evacuation, the sealant liquid (rich in EO from the first evacuation) is mechanically mixed with the incoming air (very lean in EO). Thus the pump serves to strip the EO from the pump sealant during the second evacuation.

There are two other facts which support the concept that substantial quantities of EO became dissolved in the pump fluid:

1. In all of the experiments, the total amount of EO that reached the inlet of the scrubber represented only 25-56% of the EO charged to the sterilizer. These data are presented in Table 8-3. There appears to be no other explanation for this loss of EO.

TABLE 8-3. STERILIZER DISCHARGE STUDIES[a]--ETHYLENE OXIDE MATERIAL BALANCE

Run No.	EO into sterilizer (g)	EO into system: First evacuation (g)	EO into system: Second evacuation (g)	EO into system: Total (g)	Percent of sterilizer charge (%)
4	150	29.5	9.3	38.8	25.4
5	153	34.7	16.5	51.3	33.5
6	153	58.7	27.3	86.2[b]	56.3
7	155	40.0	18.8	58.8	37.9

[a] Additional experimental data are presented in Appendix G.

[b] At the end of run 6, the pump was allowed to run for an additional 30 min with the sterilizer open to the atmosphere. This procedure allowed air to pass through the vacuum pump and into the inlet of the system. Analytical data from samples taken at the inlet show that 116 g of EO had been eluted from the sealant liquid (ethylene glycol) of the pump (see Appendix G).

2. Elution of the pump liquid with pure air resulted in high concentrations of EO in the outlet gases and relatively large total quantities of EO (see footnote to Table 8-3). The source of this EO must be release of EO by the sealant liquid.

Before the start of run 6, the sterilizer was inadvertently allowed to discharge at a time when the system was not operating. This allowed high concentrations of EO (5-10%) to come in contact with the outlet area of the system. This EO dissolved in moisture known to be present in the outlet area and resulted in contamination of subsequent outlet samples taken during run 6 (see Appendix G). EO concentrations in the range 5-25 ppm were detected during this run; no EO had been detected in the outlet during the previous runs.

The outlet area was thoroughly purged with nitrogen gas and air, and run 6 was repeated (run 7). As in runs 4 and 5, no EO was detected in the outlet during run 7.

8.4 RESULTS OF EXPERIMENTS IN WHICH ETHYLENE OXIDE WAS ADDED DIRECTLY TO ACID-HYDROLYSIS SYSTEM

Additional experiments were performed to supplement the analytical data obtained during sterilizer discharge. Ethylene oxide was added (at a controlled rate) to the system at a point located upstream from the system. The flow rate was maintained for approximately 7 min, allowing multiple samples to be taken on each side of the system.

The selected flow rate level was based upon the flow rate capacity of the system, which was approximately 2.5 cfm. The feedstock for the EO additions was the sterilizing mixture (12/88). The test procedures were very similar to the tests of the system during sterilizer discharge. The EO was added to the system using an evaporator device and a calibrated rotameter. As in the other studies, samples were taken on each side of the system at approximately 40-sec intervals. Temperature and flow rate were also determined as in the sterilizer discharge studies.

The results of these studies are presented in Table 8-4 and in Appendix H. As indicated in Table 8-4, all of the tests showed very high EO destruction efficiencies, greater than 99.999%. No EO was detected in the outlet of the scrubber, and the limit of detection was 1 ppm.

TABLE 8-4. SUMMARY OF EXPERIMENTS IN WHICH ETHYLENE OXIDE WAS ADDED DIRECTLY TO THE ACID-HYDROLYSIS SYSTEM[a]

Run No.	EO concentration at inlet (%)	Flow rate (scfm)	EO into system (g)	EO emissions from system (ppm)	EO emissions from system (mg)	Observed EO destruction efficiency (%)
1	17.55-24.37	2.5	190	< 1	< 0.8	> 99.999
2	19.22-22.67	2.5	56	< 1	< 0.2	> 99.999
3	21.05-24.38	2.5	213	< 1	< 0.8	> 99.999

[a] Additional data are presented in Appendix H.

SECTION 9.0

COST ESTIMATE FOR ACID-HYDROLYSIS SCRUBBING SYSTEM

This type of control device is less developed than catalytic oxidation, and although a pilot unit is installed at a hospital, the final design of the hospital unit remains unfixed at this date. Therefore, the costs estimated here are primarily costs provided by the system vendors. A summary of the operating cost estimates is presented in Table 9-1.

9.1 CAPITAL COSTS

A base equipment cost estimate of $15,000 has been supplied by the vendor of the hospital scrubber which was tested.[1] However, the vendor recommends installing a recirculating vacuum pump to replace the current once-through vacuum pump or water ejector currently on most sterilizers. Doing so eliminates drain emissions which, as shown by test data presented in Section 6.0, can be a significant EO emission source. With a recirculating vacuum pump the equipment cost is estimated to be approximately $20,000.[1] These cost estimates represent target prices for the vendor and have not yet been firmly established. Installation cost was estimated at 20-30% of the equipment cost. The hospital system can only treat the discharge of one sterilizer at a time. However, if a hospital has multiple sterilizers they can all be ducted to the system as long as the sterilizers are timed so as not to discharge simultaneously.

TABLE 9-1. COST ESTIMATES FOR ACID-HYDROLYSIS SYSTEM

	Small	Large
Capital Costs		
Equipment Cost:	$15,000 - 20,000	$15,000 - 20,000
Installation Cost:	4,000 - 6,000	4,000 - 6,000
Total Equipment Cost:	$19,000 - 26,000	$19,000 - 26,000
Annual Operating Cost		
Shipping Spent Solution to Vendor for Disposal:[a]	32 - 114	590 - 2,125
Replacement Solution (Materials and Shipping):[a]	35 - 117	648 - 2,183
Maintenance Labor Cost (Estimated):	500	1,675
Pump Electricity:	8	40
Estimated Total Annual Operating Cost:	$ 575 - 739	$ 2,953 - 6,023

[a] Shipping costs estimated using information from Reference 3.

9.2 ANNUAL OPERATING COSTS

As shown in Table 9-1, the operating costs associated with the hospital system include the costs of spent solution disposal, the cost of Table 9-1 solution replacement, the cost of labor for maintenance and operation, and the cost of electricity for the pump that recirculates the fluid in the system. Each of the operating costs is discussed in more detail below.

9.2.1 Disposal and Replacement Costs

The predominant operating costs for the acid-hydrolysis system are for replacement solution and disposal of spent liquor. The cost of these functions is directly related to the amount of EO used by the hospital. In order to produce a range of operating costs, model hospitals were developed for evaluation (see Table 9-2). The small hospital model is represented by one small sterilizer (9.0 ft^3) operating once per day 360 times per year. This sterilizer is typically charged with 2.5 lb of 12/88 (0.3 lb of which is EO). Thus, total annual EO consumption is 108 lb/year. For the large model hospital, represented by two large sterilizers (30 ft^3) and one small sterilizer (9.0 ft^3), the EO consumption is approximately 2,016 lb annually.

The system can absorb and convert approximately 450 lb of EO to ethylene glycol before the scrubbing solution must be replaced.[1] The number of replacements required annually can be determined by dividing the annual EO consumption by the system capacity. Once the recirculating solution reaches approximately 60% ethylene glycol by weight, the spent solution must be disposed of and fresh solution replaced.

Although the solution at the time of disposal is not classified as a hazardous waste, it is still highly acidic and must be neutralized prior to discharge. However, most hospitals will lack the capability for performing the neutralization and discharge themselves. For this reason, the vendor of the technology investigated an approach to both disposal and replacement that will place a minimum of technical capability burden on hospitals. According to this approach, hospitals will ship the spent solution back to the vendor

TABLE 9-2. MODEL HOSPITAL PARAMETERS FOR ACID-HYDROLYSIS OPERATING COST ESTIMATION

Type of model EO consumer	Chamber size (ft^3)	Number of chambers	EO emissions per cycle per chamber (lb)	Cycles per year per chamber	Annual EO consumption (lb/yr)
Small	9	1	0.3	360	108
Large	30	2	1.0	900	1,800
	9	1	0.3	720	216
		3			2,016

where the neutralization and either reuse or disposal operations will take place. This approach avoids the necessity of hospital personnel neutralizing the highly acidic solution with concentrated caustic. If this disposal solution is not available, then each hospital must be prepared to accept disposal responsibility for waste scrubbing liquid.

In the past, solutions of this kind have been accepted by publicly owned treatment works (POTWs), provided that a chemical analysis of the spent solution is completed prior to discharge.[1] At large hospitals, where frequent solution replacements will be necessary, the shipping costs may become high enough to encourage the hospital to neutralize their own solution and discharge it to their local POTW.

The cost ranges presented in Table 9-1 only represent the case where a hospital will ship the solution to the vendor for disposal. However, even if the hospital disposed of the solution themselves, the hospital would need to pay the cost of a fresh solution. Since the raw materials for the solution are inexpensive, the cost of the replacement solution will almost equal the cost to ship the solution from the vendor to the hospital. Thus the shipping expenses cannot be eliminated by on-site neutralization and disposal.

9.2.2 Maintenance Labor Costs

The labor cost associated with the hospital acid-hydrolysis system was estimated using two components, a monthly inspection, and labor associated with solution replacement. Inspection time of 1 hr monthly was estimated to be necessary. For solution replacement, the labor required to ship the spent solution and order and receive the fresh solution was estimated to be 8 hr.

9.2.3 Pump Electricity

The energy costs for the acid-hydrolysis system are very low compared to the catalytic oxidation system. Essentially, the only energy cost is the electricity for the pump which circulates the acid solution. The pump capacity is 1 hp or less according to the vendor, and it runs only during the sterilizer discharge. Electricity requirements for this pump were estimated to be $8 annually for the small model hospital and $40 annually for the large hospital.[2]

9.3 REFERENCES FOR SECTION 9.0

1. Telecon. B. Nicholson, MRI, with confidential vendor. August 17, 1987.

2. Neveril, R. B., GARD, Inc. Capital and Operating Costs of Selected Air Pollution Control Systems. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-450/5-80-002 (NTIS PB80-157282). December 1978.

3. Telecon. B. Nicholson, MRI, with D. McCollen, Yellow Freight Systems, Inc., Durham, North Carolina. August 17, 1987. Shipping costs for ethylene glycol.

APPENDIX A

CHEMICAL REACTIONS OF ETHYLENE OXIDE RELEVANT TO POTENTIAL STERILIZER EMISSION CONTROL OPTIONS

Oxidation and hydrolysis are discussed in the body of this report as important chemical reactions for potential emission control options for hospital sterilizers. Other reactions that were considered are discussed below.

1. Industrial Products from Ethylene Oxide

A general review was made of all potentially important chemical reactions of EO which might form the basis for a sterilizer control technology.[1] Special emphasis was placed on those reactions which form the basis of industrial production technology based on EO.

Almost all (98 percent) of the EO produced in the U. S. (3×10^9 kg/yr, 1983) is used in the production of other chemicals.[2] Table A-1 lists the products produced from EO and the percentages of total production that each product represents.

In the following paragraphs, a very brief review is presented of the reactions upon which these products are based as well as other related EO reactions which were considered.

2. Reaction with Alcohols

Ethylene oxide reacts with alcohols (Equation 1) to produce the monoethers of ethylene glycol,

$$\mathrm{EO} + \mathrm{ROH} \qquad \mathrm{RCH_2CH_2OH} \qquad (1)$$

$$(\mathrm{R} = \mathrm{C_2H_5} = \text{Cellosolve})$$

---

[1] The sources of information were basically the "Kirk-Othmer Encyclopedia of Chemical Technology," First, Second and Third Editions, 1950, 1966, and 1980. Subject topics that were examined included "Ethylene Oxide" plus entries concerning various EO products. Other references cited by this source were also examined.

[2] Source: R. Conway et al. Environmental Science and Technology, 17, 107-112 (1983).

TABLE A-1. INDUSTRIAL PRODUCTS PRODUCED FROM EO

Product	Percent of total EO production
Ethylene glycol	60
Surfactants	11
Ethanolamines	7
Glycol ethers	7
Others	15

alcohols. Since hydrolysis is a competing reaction, the processes are carried out under anhydrous conditions. Because of the high humidity required for sterilization, anhydrous conditions would be troublesome to obtain, and this reaction would probably not be applicable for EO control.

3. Reaction with Ethylene Glycol

Ethylene oxide reacts with ethylene glycol to produce poly(ethylene glycols) (Equation 2).

$$\mathrm{EO + HOCH_2CH_2OH \xrightarrow[\substack{NaOH\\4\ ATM}]{130^\circ C} HOCH_2(CH_2OCH_2)_nCH_2OH} \qquad (2)$$

Polyoxyethylene
Poly(ethylene glycol)
$n = 5\text{-}10$

The products are used in pharmaceutical ointments, topical formulations, and cosmetics. Although the products are harmless, the relatively high temperature and high pressure of this reaction probably preclude its use in control technology.

4. Reaction with Ammonia

Ethylene oxide reacts with ammonia to produce the ethanolamines (Equation 3) and similarly with amines to produce substituted ethanolamines (Equation 4).

$$\mathrm{EO + \underset{(Ammonia)}{NH_3} \longrightarrow \begin{array}{ll} HOCH_2CH_2NH_2 & Ethanolamine \\ (HOCH_2CH_2)_2NH & Diethanolamine \\ (HOCH_2CH_2)_3N & Triethanolamine \end{array}} \qquad (3)$$

$$\mathrm{EO + \underset{(Amines)}{R_2NH} \longrightarrow R_2NCH_2CH_2OH \quad \begin{array}{l} Substituted \\ ethanolamine \end{array}} \qquad (4)$$

All of these materials are important commercial products used in the manufacturer of detergents and other applications. These reactions were not considered useful for EO control technology because of the objectional odors involved (ammonia and the amines) and the fact that the products might be converted to carcinogenic nitrosamines in the environment.

5. Reduction

Ethylene oxide can be reduced to ethanol (Equation 5), a harmless product, but this reaction requires hydrogen under high pressure, or the handling of metallic sodium which is hazardous.

$$\text{EO} \xrightarrow[\substack{\text{or sodium amalgam} \\ \text{(reduction)}}]{\substack{\text{catalytic} \\ \text{hydrogenation}}} \underset{\text{(ethanol)}}{CH_3CH_2OH} \qquad (5)$$

6. Reactions with Mineral Acids

Ethylene oxide reacts with minerals acids to produce ethylene halohydrins (Equation 6).

$$\text{EO + } \underset{\text{(anhydrous)}}{\text{mineral acids}} \xrightarrow[X = CL,\ CN]{HX} \underset{\substack{\text{(ethylene} \\ \text{halohydrin)}}}{HOCH_2CH_2X} \qquad (6)$$

These reactions are performed under anhydrous conditions, and the products would be expected to be relatively toxic.

7. Reaction with Organic Acids

Organic acids also react with EO (Equation 7) to produce important industrial products that are not toxic. However, the reactions are performed under anhydrous conditions because of the competing reaction of hydrolysis.

$EO + RCO_2H$ (organic acid) $HOCH_2CH_2OCOR$ (ethylene glycol ester) (7)

8. Thermal Decomposition and Polymerization

Ethylene oxide undergoes thermal decomposition (Equation 8) and polymerization (Equation 9), but these reactions are probably not suitable for control technology.

EO $\overset{500^{\circ}C}{\underset{\text{thermal decomposition}}{}}$ (8)

CH_4	Methane
CO	Carbon monoxide
C_2H_6	Ethane
H_2	Hydrogen
C	Carbon

EO $\overset{\text{catalyst}}{\underset{\text{polymerization (explosive hazard)}}{}}$ Dioxane and polymers (MW 10,000 - 70,000) (Carbowax) (9)

APPENDIX B

REVIEWS OF CONTROL TECHNOLOGY CONCEPTS WHICH WERE ELIMINATED

Of the eight control technologies which were selected for evaluation, five were eliminated. These concepts, and the reasons that they are not acceptable, are discussed below.

1. Thermal Incineration

This concept was eliminated on the basis that incineration of chlorinated fluorocarbons (CFC) would produce toxic and corrosive by-products including phosgene, hydrochloric acid, hydrofluoric acid, and other products equally unacceptable. Thermal incineration could not be used without a pretreatment step that separates EO from CFC. Since this would necessitate another process and an additional costly unit operation, incineration was not considered further.

2. Condensation

This concept was eliminated on the basis that an explosion hazard would be created. Condensing the sterilizer gas to a liquid would require that the unit be operated in the explosive range of ethylene oxide. Condensation is employed for EO recovery in a commercial sterilizing facility, but the process requires all explosion-proof hardware in a separate room. The expense to achieve this level of safety would be prohibitive for hospital sterilizers. Other disadvantages include low recovery efficiency (60 to 70 percent) and the required reformulation to achieve the 12:88 ratio before reuse is possible.

3. Corona Discharge

This technique employs a high-voltage, low- current electric field across a gap between a microneedle and a plate. This field strips electrons from the passing gas molecules. The resulting free electron bombardment breaks molecular bonds. The new molecules recombine downstream in a random fashion creating many by-products. The chemistry of gases undergoing a controlled plasma reaction is not yet fully understood. As Table 2 shows, Westinghouse is currently developing this technique for NO_x and SO_x removal in boiler stacks. Efficiencies are low, and products can be new and unknown compounds. Westinghouse representatives said that they have enough experience to predict that the decomposition products of Freon are likely to be hydrochloric and hydrofluoric acids among other things. According to Westinghouse, at least 3 years of further study are needed before the technique would be commercially available. Thus, based on the information provided by Westinghouse concerning toxic by-products, corona discharge was eliminated from further consideration.

4. Ultraviolet Photolysis

This process was also eliminated because of toxic by-product formation. Ethylene oxide spontaneously decomposes when irradiated by ultraviolet (UV) light. Unfortunately, Freon also decomposes under these conditions to form free-radical chlorine and fluorine. Developers of this technique have had success if the gas treated is pure EO, but if Freon is present, a sticky polymeric substance is formed which coats the UV tubes and blocks further UV radiation from reaching the gas stream. Thus, since all hospitals use 12/88, this technique cannot be used unless further refinements are made.

5. Ozonation

In this process, ozone would oxidize EO and leave the CFC unreacted. However, ozonation is generally used commercially only in situations requiring the destruction of very small quantities of an odorous gas. The largest ozone generator readily available, beside being economically infeasible, could not provide enough ozone to oxidize the entire sterilizer load as fast as it exited the sterilizer. An alternate plan was considered in which the spent 12/88 was stored and gradually released to the ozonator. However, the ancillary equipment required, plus the high capital cost of the ozonator, still did not make this method economically attractive. Further, it was felt there were too many unknown factors involved with this technique: the exotherm from the EO/O_3 reaction, Freon stability under all reaction conditions, control equipment with feedback loops to check O_3 emissions were required, and the equipment itself requires moderate to high maintenance.

APPENDIX C

ANALYTICAL PROCEDURES

APPENDIX C

ANALYTICAL PROCEDURES

1.0 DETERMINATIONS OF ETHYLENE OXIDE DESTRUCTION EFFICIENCY

The sampling and analysis methods were identical for both the sterilizer discharge tests and the EO addition tests. The THC analyzer was placed in line upstream of the catalyst system. The GC samples were taken from septum ports installed preceding and following the catalyst system, using 2.5-mL locking, gas-tight syringes. The actual septum ports were located in the lines to the THC and chloride trains. The pumps maintained a purge rate of > 1 L/min. Preliminary tests at MRI indicated that the replaceable needle/syringe lock/gas-tight syringe arrangement used allowed samples to be stored in the syringes for up to 3 hr with a loss in concentration of less than 5%. Samples were taken every 40 sec during the EO addition runs and the first half of the sterilizer discharge runs, and 1-min intervals during the second half of the sterilizer discharge runs.

The samples were injected immediately following each test into a Varian gas chromatograph, which contained two flame ionization detectors. The GC conditions are shown here:

Gas Chromatograph	Varian 2400 with dual FIDs
Separation columns	6 ft x 1/8 in. O.D. SP-Alloy packed with 80/100 Porapak PS
Oven temperature	100°C
Carrier gas/flow rate	Helium, 30 mL/min
Detector temperature	260°C
Injector temperature A/B	190/210°C

Both inlet and outlet sides of the system were calibrated twice daily with 90.7 ppm and 1035 ppm EO in nitrogen standards prepared by Scott gases (see Table C-1). The THC analyzer was calibrated twice daily with zero air and 1,035 ppm EO.

All data was recorded on both computer diskettes and a strip chart recorder. The sample concentrations were determined by dividing the actual peak area by a reference factor based on that day's calibration data. The initial and final averages for each calibration gas were entered in a regression curve fit program forcing the y-intercept through the origin. The slope of this line was used as the reference factor.

2.0 CHLOROFLUOROCARBON DECOMPOSITION STUDIES

A midget impinger sampling train was used to trap any chloride which may have resulted from CF_2Cl_2 degradation in the catalyst bed. The train consisted of two impingers containing 0.1 N sodium carbonate solution. The sample gas volume through the train was measured using a dry test meter. The samples were recovered into Nalgene bottles and returned to MRI for analysis using ion chromatography, according to ASTM D4327-84.

Prior to making new calibration standards for the ion chromatograph, several samples were analyzed to determined an approximate concentration range. None of the samples indicated any chloride present, with the instrument running at a detection limit of 200 ppb. The detection limit was determined using standards prepared for a previous project. The limit was based on the chloride concentration corresponding to a peak at 40% of the lowest calibration standard of 500 ppb. The carbonate peak coincided with the retention time of fluoride, so no fluoride could have been detected, had it been present. To verify that the standard concentrations used had not varied significantly, very low concentration performance samples were prepared and analyzed. Although the results of this analysis were outside the Data Quality Objectives of 95% accuracy specified in the QAPP, the actual deviations were very small. The results of the analysis are shown below:

TABLE C-1. SUMMARY OF CALIBRATION RESULTS
Catalytic Oxidation System

Run, channel	Calibration gas (ppm)	Initial peak area (1000 counts)	Final peak area (1000 counts)	RPD (%)[a]	Reference factor[b]
1-A	90.7	197.3	192.0	2.7	2,112
	1,035	2,225	2,146	3.6	
1-B	90.7	232.2	224.3	3.5	2,468
	1,035	2,605	2,503	4.0	
Drain 1-A	50	75.7			2,060
	500	1,033			
2,3-A	90.7	178.1	166.6	3.3	1,776
	1,035	1,963	1,712	13.7	
2,3-B	90.7	214.3	217.9	1.7	2,278
	1,035	2,357	2,356	0.03	
4-A	90.7	163.0	151.5	7.3	1,691
	1,035	1,806	1,693	6.5	
4-B	90.7	201.8	206.2	2.2	2,164
	1,035	2,196	2,282	3.8	
Drain 4-A	50	74.0			2,141
	500	1,074			
5,6-A	90.7	210.5	232.9	10.1	2,386
	1,035	2,326	2,613	11.6	
5,6-B	90.7	229.3	244.9	6.6	2,499
	1,035	2,534	2,636	3.9	
7-A	1,035	1,993	2,300	14.3	2,075
7-B	90.7	241.5	248.4	2.8	2,538

---

[a] Relative Percent Deviation, $\left|\frac{\text{Initial-Final}}{\text{Average}}\right| \times 100$

[b] Calculated using Linear Least Squares Fit forcing a zero-intercept or

$$m = \sum \frac{x_i y_i}{x_i^2}$$

Actual concentration	Found concentration	Percent accuracy
2.83 ppm	2.43 ppm	86%
1.42 ppm	1.21 ppm	85%

The results did not indicate sufficient need to prepare new calibration standards since no detectable levels of chlorides were found in the samples.

3.0 DETERMINATION OF ETHYLENE OXIDE IN VACUUM PUMP DRAIN WATER

Samples of the water discharge from the vacuum pump were taken using a dipper. Respiratory protective equipment was used during the sampling and transfer to 40-mL vials. Notation was made of the exact time that the samples were taken. The vials were equipped with septa-lined caps and were filled to the top of the vial.

One microliter of these samples was injected into the inlet side of the GC under the conditions specified earlier. The standards were prepared by injecting a known volume of 12/88 gas into a known volume of water in an air-tight vial. The standards were prepared at 50 and 500 ppm levels and stored on ice between injections. The data were treated in the same manner as previously described GC samples.

4.0 DETERMINATIONS OF ACID SCRUBBER EFFICIENCY

The sampling and analysis methods were identical for both the sterilizer discharge tests and the EO addition tests. The inlet samples were taken from septum ports installed just prior to the scrubber system, using procedures described earlier. The outlet samples were taken from an injection tee installed on a gas circulating loop which withdrew about 1 L/min from the system, past the sample port, through a pump and then returned to the system about 1 ft downstream. All components between the port and system were Teflon or stainless steel. Dry gas meter readings and samples were taken every 40 sec during Runs 1 through 6 and at 1 min intervals during Run 7.

The samples were analyzed immediately following each test using the Varian gas chromatograph described earlier. Both inlet and outlet detectors were calibrated twice daily: 1% and 2% EO standards were used for the inlet side and 49.3 and 90.7 ppm standards were used for the outlet side (see Table C-2). The differences in GC conditions are listed below:

Injector temperatures	185-210°C
Detector temperatures	188-220°C

The concentrations of the inlet samples were substantially higher (15,000 ppm) than those obtained from the inlet of the catalytic oxidation system (200-1,500 ppm). The inlet samples were diluted in the syringes in order to bring the concentrations down to the range of the calibration standards. The technique involved diluting 0.25 mL of sample to 2.5 mL with ambient air. The syringe was then locked and the plunger depressed and returned to the 2.5 mL mark to assure even mixing. Then 2.07 mL of this mixture was expelled into a waste bag. The remaining 0.43 mL was then diluted to 1.0 mL with ambient air.

A verification of this technique was performed by diluting one of the calibration standards with three different syringes at the beginning of each day, and the average of those dilutions was used to calculate actual sample concentrations. A more detailed description, including actual calculations is shown below.

5.0 DILUTION METHODOLOGY AND CALCULATIONS

The dilution scheme described above was developed to provide an efficient, accurate method of bringing the samples to the range of the standards. The first step in determining the exact volumes needed was to measure the dead volume in the needle, syringe lock, and syringe. This was done by diluting an apparently known volume of calibration gas with a known volume of ambient air. If the dead volume were zero, the dilution would indicated 10% of the original peak area of the calibration gas, using 0.25 mL calibration gas diluted to 2.5 mL with ambient air. However, since the dead volume filled with calibration gas is pulled into the syringe body with the ambient air, the

TABLE C-2. SUMMARY OF CALIBRATION RESULTS
Acid Hydrolysis System

Run, channel	Initial Calibration gas	Final peak area (1000 counts)	peak area (1000 counts)	RPD (%)[a]	Reference factor[b,c]
1,3-A	1.0%	28,261	28,656	1.4	2,705
	2.0%	51,626	55,020	6.4	
1,3-B	48.3 ppm	162.4	154.7	4.9	3,394
	90.7 ppm	308.0	313.4	1.7	
1,3-A	Dilution check - 1.0% in syringe A	2,420			2,393 (8.5%)
	B	2,419			
	C	2,341			
4-A	1.0%	25,261	28,075	10.6	2,524
	2.0%	47,858	51,566	7.5	
4-B	48.3 ppm	161.2	155.5	3.6	3,421
	90.7 ppm	319.3	308.7	3.4	
4-A	Dilution check - 1.0% in syringe A	2,295			2,203 (8.8%)
	B	2,292			
	C	2,023			
5,6-A	1.0%	24,490	22,568	8.2	2,238
	2.0%	45,394	42,865	5.7	
5,6-B	48.3 ppm	158.0	154.9	2.0	3,377
	90.7 ppm	312.5	307.3	1.7	
5,6-A	Dilution check - 1.0% in syringe A	2,083			2,093 (8.6%)
	B	2,254			
	C	1,942			
7-A	1.0%	23,392	21,489	8.5	2,152
	2.0%	43,909	41,144	6.5	
7-B	48.3 ppm	155.2	154.7	0.3	3,319
	90.7 ppm	306.9	300.9	2.0	
7-A	Dilution check - 1.0% in syringe A	1,986			1,982 (8.5%)
	B	2,046			
	C	1,914			

---

[a] Relative Percent Deviation, $\left| \frac{\text{Initial-Final}}{\text{Average}} \right| \times 100$

[b] Calculated using Linear Least Squares Fit forcing a zero-intercept or

$$m = \sum \frac{x_i y_i}{x_i^2}$$

[c] Number in parentheses is an average dilution value from three syringes, three injections each, used to determine concentrations of diluted high level samples.

dilution is lower than 10%. The actual value of the dilution allows the dead volume contribution to be calculated, according to the equation shown here:

(initial vol) (conc) + (vol air added) (conc) = (final vol) (conc)

Where: conc = concentration of calibration gas in percent relative to initial calibration gas concentration

$(0.25 + x)\ (100\%) + (2.25)\ (0\%) = (2.5 + x)\ (18.4\%)$

Where: x = Dead volume

18.4% = Actual concentration determined from triplicate analysis conducted immediately prior to field tests (after diluting 0.25 mL of calibration gas to 2.5 mL with ambient air)

The second calculation, utilizing the value calculated above for the dead volume, determines what volume of this calibration gas/air mixture is needed in 1 mL of sample to give a final concentration equal to 10% of the original calibration gas, 1 mL being the injection volume. This equation also follows the generic formula shown above. With actual values substituted, it is:

$(y + 0.25)\ (18.4\%) + (1-y)\ (0\%) = (1 + 0.25)\ (10\%)$

Where: y = Volume of calibration gas needed for 10% dilution

0.25 = Dead volume from first equation

10% = Desired final concentrations

Solving the above equation for y gives an initial desired volume of 0.43 mL for the second portion of the dilution. As mentioned previously in the text, this two-step process was performed using three different syringes, three times each, as part of the daily initial instrument calibration process. An average dilution value was used in conjunction with the standard reference factor to calculate the actual sample volumes.

APPENDIX D

EXPERIMENTAL DATA
CATALYTIC OXIDATION SYSTEM
STERILIZER DISCHARGE EXPERIMENTS

NOTES TO APPENDIX D

1. GC CALCULATIONS

a. The area under the curve is the average of the current and previous points times the time interval since the GC samples are near instantaneous grab samples.

b. The EO emissions in grams are the area in ppm*min times 0.019 obtained from the equation:

$$\text{g EO} = \frac{\text{ppm}(\mu\text{L/L}) * \text{min} * 370\ \text{ft}^3\text{/min} * 28.32\ \text{L/ft}^3 * 1.83\ \text{g/L}}{10^6\ \mu\text{L/L}}$$

The catalyst is assumed to be leak-free, thus the outlet flow is the same as the inlet flow.

c. For the water samples, the emission factor is 0.0033 times the curve area from:

$$\text{g EO} = \frac{\text{ppm (mg/L)} * \text{min} * 3.3\ \text{L/min}}{1{,}000\ \text{mg/g}}$$

2. THC CALCULATIONS

a. The THC responds to the sum of all organics. The correction from ppm as EO to Est EO (ppm) uses measured response factors for 1000 ppm mixtures of EO and CF_2Cl_2 in nitrogen. Assuming that the inlet vapor remains at 12% EO, 88% R-12 (w/w) the EO fraction would be 64% of the total signal. A moderate nonlinearity of CF_2Cl_2 response was ignored. Also, in runs 1, 4, and 7 the losses into the water probably have shifted the ratio to some extent because of the high solubility of EO and the low solubility of CF_2Cl_2.

b. The area under the curve calculation is the time from the previous reading times the logger reading in ppm. This is because the logger records the average of all scans since the previous entry. Where noise problems caused skipped points the average covers the entire period, not just the last 10 sec.

c. The same 0.019 factor for Est EO emissions is used.

3. NOTE ON FLOW MEASUREMENTS

Because of the difficulty of measuring the low delta P across the pitot, no attempt to correct the flow according to the delta P measured during each run was made. The inlet flow is assumed equal to the traverse run on June 8 (370 ft^3/min). The measurement precision is about ±50 cfm. The catalyst bed had Magnehelic gauges monitoring the pressure drop across each stage. These gauges never varied during any test.

The water flow rate is an average of four measurements on June 9 and 10. The flow rate was never constant. The measured average has an error limit of about 20%.

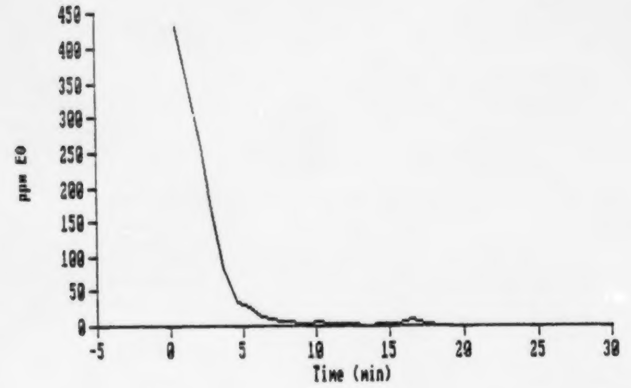
RUN 1
GC DATA - INLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min)	EO (g)
Start	1155.54		1155.9	-.0		
I-1	1156.20	430.11	1156.3	.4	93.2	1.771
I-3	1158.00	265.69	1158.0	2.1	579.8	11.017
I-4	1158.40	177.84	1158.7	2.8	147.8	2.809
I-5	1159.30	84.66	1159.5	3.6	109.4	2.078
I-6	1200.30	35.11	1200.5	4.6	59.9	1.138
I-7	1201.19	25.68	1201.3	5.4	24.8	.472
I-8	1202.07	14.21	1202.1	6.2	16.0	.303
I-9	1202.48	11.18	1202.8	6.9	8.7	.165
I-10	1203.28	8.34	1203.5	7.6	6.5	.124
I-11	1204.06	8.07	1204.1	8.2	5.2	.099
I-12	1204.45	4.70	1204.8	8.8	4.2	.079
I-13	1205.27	4.61	1205.5	9.5	3.3	.062
I-14	1206.04	6.21	1206.1	10.2	3.3	.063
I-15	1206.43	4.43	1206.7	10.8	3.5	.066
I-16	1207.20	2.46	1207.3	11.4	2.1	.040
I-17	1208.20	3.77	1208.3	12.4	3.1	.059
I-18	1209.21	1.56	1209.4	13.5	2.7	.051
I-19	1210.20	4.99	1210.3	14.4	3.2	.061
I-20	1211.25	2.11	1211.4	15.5	3.8	.073
I-21	1212.21	9.24	1212.4	16.5	5.3	.101
I-22	1213.20	3.50	1213.3	17.4	6.3	.119
I-23	1214.20	1.09	1214.3	18.4	2.3	.044
I-24	1215.20	1.06	1215.3	19.4	1.1	.020
I-25	1216.20	.84	1216.3	20.4	1.0	.018
I-26	1217.20	.82	1217.3	21.4	.8	.016
I-27	1218.20	.75	1218.3	22.4	.8	.015
I-28	1219.20	.70	1219.3	23.4	.7	.014
I-29	1220.20	1.05	1220.3	24.4	.9	.017
I-30	1221.20	.30	1221.3	25.4	.7	.013
I-31	1222.20	.30	1222.3	26.4	.3	.006
I-32	1223.21	.51	1223.4	27.5	.4	.008
I-33	1224.20	.77	1224.3	28.4	.6	.012
				Totals=	1101.6	20.93

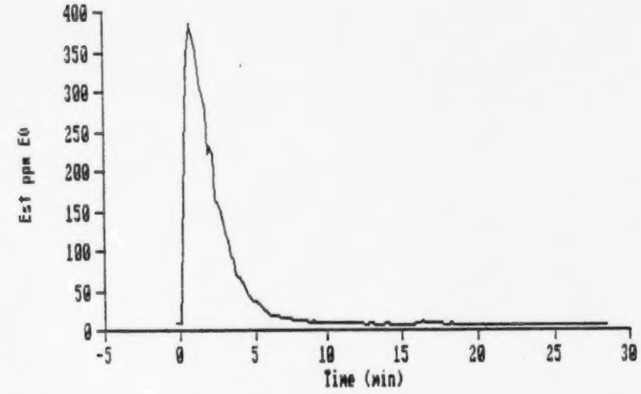
RUN 1
GC DATA - OUTLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
Start	1155.54		1155.9	-.0		
O-1	1156.20	0.00	1156.3	.4	.0	.000
O-2	1157.07	.62	1157.1	1.2	.2	.005
O-3	1158.00	0.00	1158.0	2.1	.3	.005
O-4	1158.40	0.00	1158.7	2.8	.0	.000
O-5	1159.30	.08	1159.5	3.6	.1	.001
O-6	1200.17	.37	1200.3	4.4	.2	.003
O-7	1201.19	.24	1201.3	5.4	.3	.006
O-8	1202.07	.18	1202.1	6.2	.2	.003
O-9	1202.48	.22	1202.8	6.9	.1	.003
O-10	1203.28	.26	1203.5	7.6	.2	.003
O-11	1204.06	.59	1204.1	8.2	.3	.005
O-12	1204.45	.26	1204.8	8.8	.3	.005
O-13	1205.27	.17	1205.5	9.5	.2	.003
O-14	1206.04	.40	1206.1	10.2	.2	.003
O-15	1206.43	.07	1206.7	10.8	.2	.003
O-16	1207.20	.17	1207.3	11.4	.1	.001
O-17	1208.20	.50	1208.3	12.4	.3	.006
O-18	1209.21	.03	1209.4	13.5	.3	.005
O-19	1210.20	.40	1210.3	14.4	.2	.004
O-20	1211.25	.22	1211.4	15.5	.3	.006
O-21	1212.21	.30	1212.4	16.5	.2	.005
O-22	1213.20	.06	1213.3	17.4	.2	.003
O-23	1214.20	.12	1214.3	18.4	.1	.002
O-24	1215.20	.46	1215.3	19.4	.3	.006
O-25	1216.20	.09	1216.3	20.4	.3	.005
O-26	1217.20	1.01	1217.3	21.4	.6	.010
O-27	1218.20	.38	1218.3	22.4	.7	.013
O-28	1219.20	.21	1219.3	23.4	.3	.006
O-29	1220.20	.01	1220.3	24.4	.1	.002
O-30	1221.20	.07	1221.3	25.4	.0	.001
O-31	1222.20	0.00	1222.3	26.4	.0	.001
O-32	1223.21	0.00	1223.4	27.5	.0	.000
O-33	1224.20	0.00	1224.3	28.4	.0	.000
				Totals=	6.8	.125

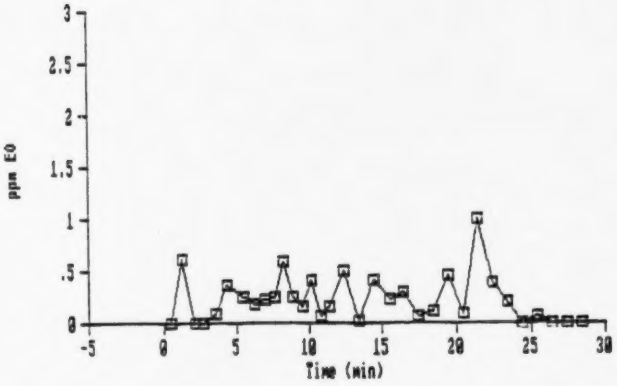
RUN #1 EO INLET CONCENTRATION



RUN #1 THC CONCENTRATION



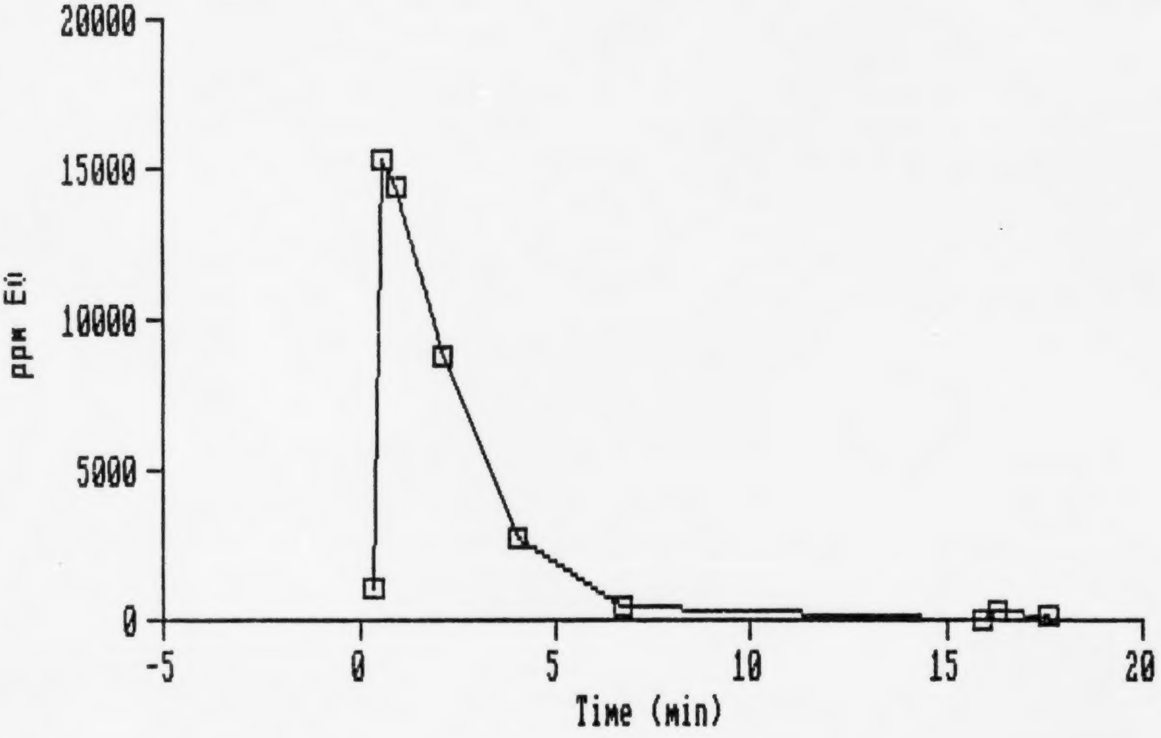
RUN #1 EO OUTLET CONCENTRATION



RUN 1
GC DATA - WATER DISCHARGE

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
Start	1155.54		1155.9	-.0		
D1003	1156.15	1027.0	1156.3	.4	179.7	.59
D1004	1156.29	15430.0	1156.5	.6	1920.0	6.34
D1005	1156.50	14394.0	1156.8	.9	5219.2	17.22
D1006	1158.00	8864.0	1158.0	2.1	13567.2	44.77
D1007	1159.55	2729.0	1159.9	4.0	11110.0	36.66
D1008	1202.39	412.6	1202.7	6.8	4293.5	14.17
D1009	1211.47	22.5	1211.8	15.9	1987.0	6.56
D1010	1212.10	322.3	1212.2	16.3	66.1	.22
D1011	1213.29	109.1	1213.5	17.6	284.0	.94
				Totals=	38626.6	127.5

RUN #1 EO WATER CONCENTRATION



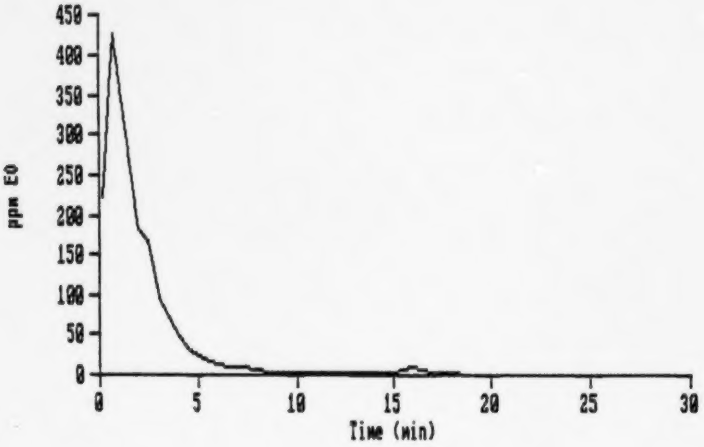
RUN 4
GC DATA - INLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
Start	1128.00		1128.0	.0		
I-1	1128.10	223.00	1128.2	.2	18.6	.353
I-2	1128.43	428.90	1128.7	.7	179.3	3.406
I-3	1129.17	312.58	1129.3	1.3	210.1	3.992
I-4	1129.57	181.14	1130.0	1.9	164.6	3.127
I-5	1130.30	167.65	1130.5	2.5	95.9	1.822
I-6	1131.07	91.94	1131.1	3.1	80.0	1.521
I-7	1132.00	51.24	1132.0	4.0	63.2	1.202
I-8	1132.35	30.22	1132.6	4.6	23.8	.451
I-9	1133.15	19.47	1133.3	5.3	16.6	.315
I-10	1133.55	12.61	1133.9	5.9	10.7	.203
I-11	1134.34	10.04	1134.6	6.6	7.4	.140
I-12	1135.14	9.42	1135.2	7.2	6.5	.123
I-13	1135.51	6.16	1135.9	7.8	4.8	.091
I-14	1136.35	4.83	1136.6	8.6	4.0	.077
I-15	1137.17	4.[illegible]8	1137.3	9.3	3.2	.061
I-16	1137.55	3.[illegible]	1137.9	9.9	2.5	.048
I-17	1138.55	3.56	1138.9	10.9	3.6	.069
I-18	1139.55	2.55	1139.9	11.9	3.1	.058
I-19	1141.00	3.83	1141.0	13.0	3.5	.066
I-20	1142.00	2.41	1142.0	14.0	3.1	.059
I-21	1143.00	3.30	1143.0	15.0	2.9	.054
I-22	1144.00	8.66	1144.0	16.0	6.0	.114
I-23	1145.00	4.66	1145.0	17.0	6.7	.127
I-24	1146.00	2.75	1146.0	18.0	3.7	.070
I-25	1147.00	1.27	1147.0	19.0	2.0	.038
I-26	1148.00	.38	1148.0	20.0	.8	.016
I-27	1149.00	.53	1149.0	21.0	.5	.009
I-28	1150.00	.62	1150.0	22.0	.6	.011
I-29	1151.00	.39	1151.0	23.0	.5	.010
I-30	1152.00	.45	1152.0	24.0	.4	.008
I-31	1153.00	.24	1153.0	25.0	.3	.007
I-32	1154.00	.40	1154.0	26.0	.3	.006
				Totals=	929.0	17.65

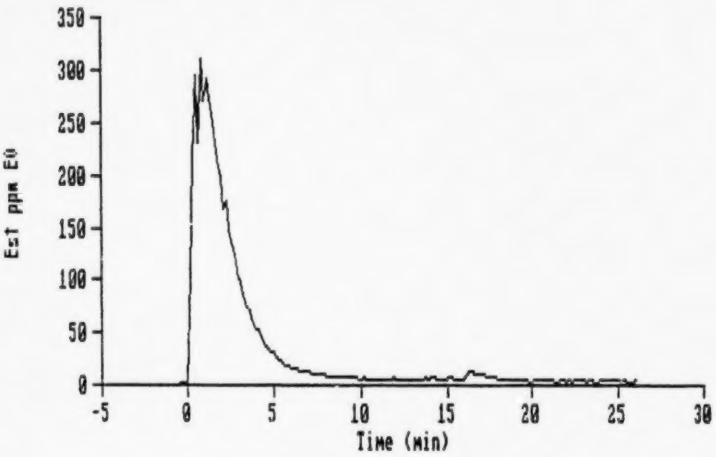
RUN 4
GC DATA - OUTLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
Start	1128.00		1128.0	.0		
0-1	1128.10	.12	1128.2	.2	.0	.000
0-2	1128.43	1.62	1128.7	.7	.5	.009
0-3	1129.17	.52	1129.3	1.3	.6	.012
0-4	1129.57	1.17	1130.0	1.9	.6	.011
0-5	1130.30	.33	1130.5	2.5	.4	.008
0-6	1131.07	.16	1131.1	3.1	.2	.003
0-7	1132.00	.05	1132.0	4.0	.1	.002
0-8	1132.35	.04	1132.6	4.6	.0	.000
0-9	1133.15	.51	1133.3	5.3	.2	.003
0-10	1133.55	.59	1133.9	5.9	.4	.007
0-11	1134.34	.26	1134.6	6.6	.3	.005
0-12	1135.14	.88	1135.2	7.2	.4	.007
0-13	1135.51	.09	1135.9	7.8	.3	.006
0-14	1136.35	.21	1136.6	8.6	.1	.002
0-15	1137.17	.81	1137.3	9.3	.4	.007
0-16	1137.55	.18	1137.9	9.9	.3	.006
0-17	1138.55	.01	1138.9	10.9	.1	.002
0-18	1139.55	.11	1139.9	11.9	.1	.001
0-19	1141.00	.31	1141.0	13.0	.2	.004
0-20	1142.00	.14	1142.0	14.0	.2	.004
0-21	1143.00	.27	1143.0	15.0	.2	.004
0-22	1144.00	.21	1144.0	16.0	.2	.005
0-23	1145.00	.17	1145.0	17.0	.2	.004
0-24	1146.00	.12	1146.0	18.0	.1	.003
0-25	1147.00	.10	1147.0	19.0	.1	.002
0-26	1148.00	.05	1148.0	20.0	.1	.001
0-27	1149.00	.09	1149.0	21.0	.1	.001
0-28	1150.00	.11	1150.0	22.0	.1	.002
0-29	1151.00	.19	1151.0	23.0	.2	.003
0-30	1152.00	.24	1152.0	24.0	.2	.004
0-31	1153.00	.86	1153.0	25.0	.6	.010
0-32	1154.00	.20	1154.0	26.0	.5	.010
				Totals=	7.8	.148

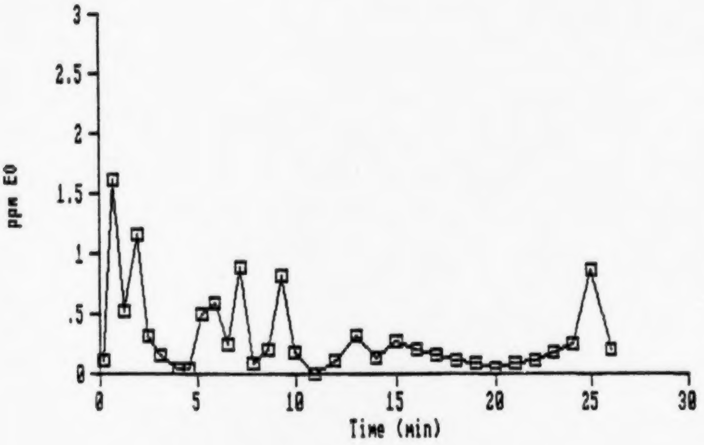
RUN #4 EO INLET CONCENTRATION

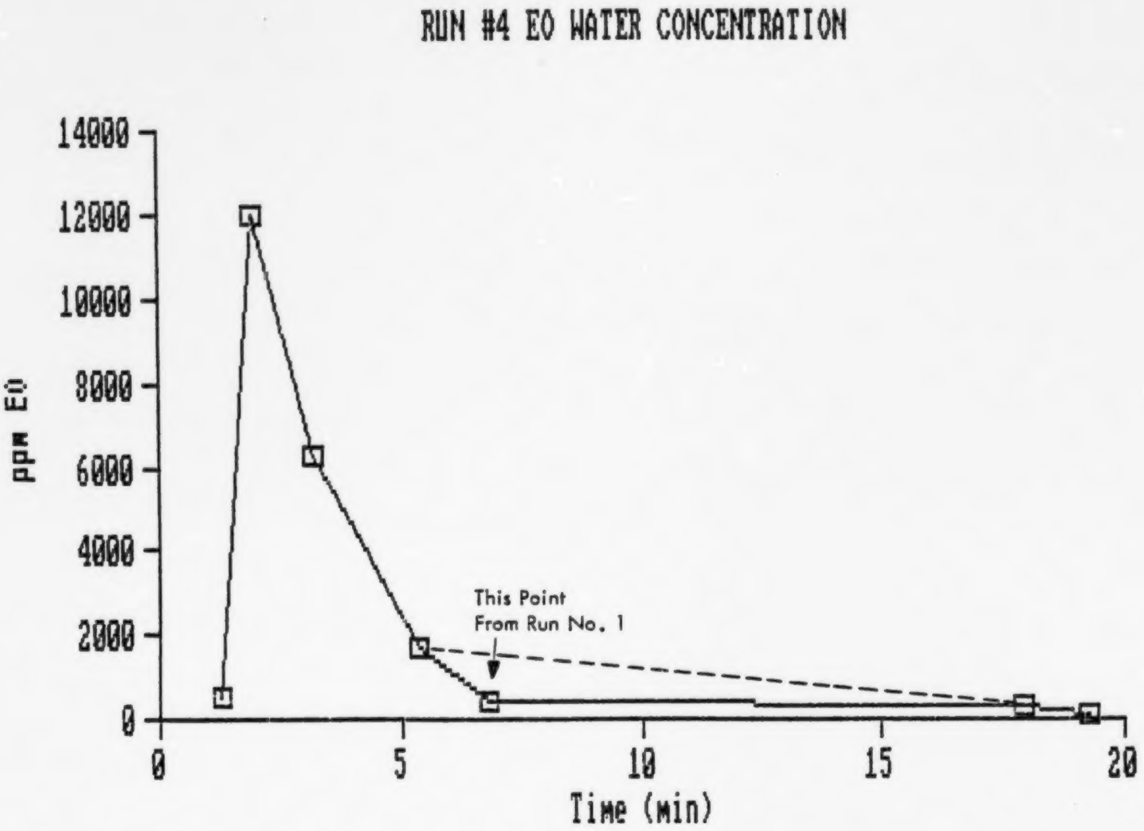


RUN #4 THC CONCENTRATION



RUN #4 EO OUTLET CONCENTRATION





RUN 4
GC DATA - WATER DISCHARGE

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
Start	1128.00		1128.0	.0		
D4003	1129.17	565.5	1129.3	1.3	362.9	1.20
D4004	1129.57	12019.0	1130.0	1.9	4194.8	13.84
D4005	1131.12	6317.0	1131.2	3.2	11460.0	37.82
D4006	1133.20	1713.0	1133.3	5.3	8565.3	28.27
D1008	1134.45	412.6	1134.8	6.8	1505.6	4.97
D4007	1145.56	330.7	1145.9	17.9	4156.3	13.72
D4008	1147.16	76.7	1147.3	19.3	271.6	.90
				Totals=	30516.5	100.7

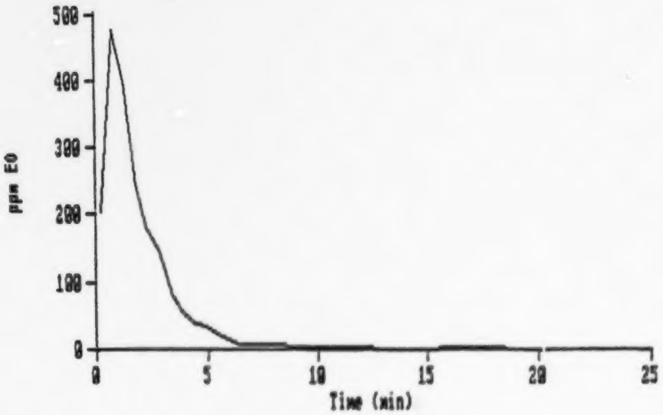
Note: No sample was available at time = 6.8. The integration of these data would result in excessively high amounts of EO because of the large area between time = 5.3 and time = 17.9 (see figure, run 4, water concentration). Therefore, the concentration obtained in run 1 at this time (see sample No. D1008 above) was used in the calculations.

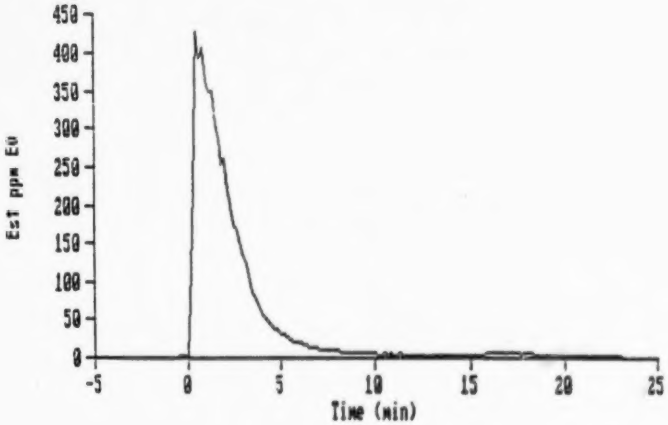
RUN 7
GC DATA - INLET

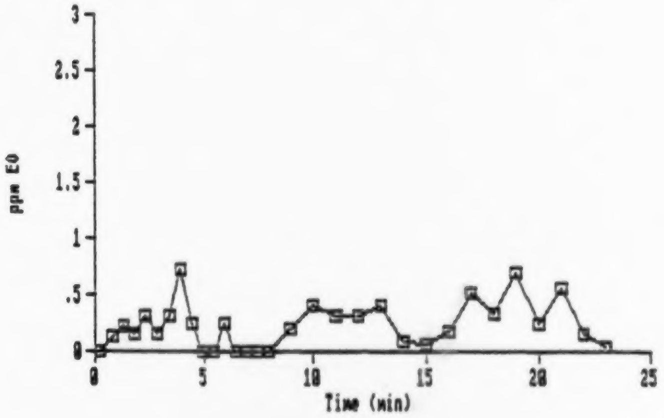
Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min)	EO (g)
Start	1157.30		1157.5	.0		
I-1	1157.43	204.63	1157.7	.2	22.2	.421
I-2	1158.16	475.37	1158.3	.8	187.0	3.553
I-3	1158.46	398.73	1158.8	1.3	218.5	4.152
I-4	1159.16	244.77	1159.3	1.8	160.9	3.057
I-5	1159.46	177.20	1159.8	2.3	105.5	2.004
I-6	1200.20	143.06	1200.3	2.8	90.7	1.724
I-7	1200.55	78.88	1200.9	3.4	64.7	1.230
I-8	1201.25	52.08	1201.4	3.9	32.7	.622
I-9	1201.55	38.91	1201.9	4.4	22.7	.432
I-10	1202.25	32.84	1202.4	4.9	17.9	.341
I-11	1202.55	22.18	1202.9	5.4	13.8	.261
I-12	1203.25	15.77	1203.4	5.9	9.5	.180
I-13	1203.55	9.18	1203.9	6.4	6.2	.119
I-14	1204.25	7.85	1204.4	6.9	4.3	.081
I-15	1204.55	6.35	1204.9	7.4	3.5	.067
I-16	1205.28	6.22	1205.5	8.0	3.5	.066
I-17	1206.30	3.26	1206.5	9.0	4.9	.093
I-18	1207.30	2.65	1207.5	10.0	3.0	.056
I-20	1209.30	1.98	1209.5	12.0	4.6	.088
I-21	1210.30	1.15	1210.5	13.0	1.6	.030
I-22	1211.30	.83	1211.5	14.0	1.0	.019
I-23	1212.30	1.04	1212.5	15.0	.9	.018
I-24	1213.30	5.04	1213.5	16.0	3.0	.058
I-25	1214.30	3.13	1214.5	17.0	4.1	.078
I-26	1215.30	2.49	1215.5	18.0	2.8	.053
I-27	1216.30	.82	1216.5	19.0	1.7	.031
I-28	1217.30	.80	1217.5	20.0	.8	.015
I-29	1218.30	.43	1218.5	21.0	.6	.012
I-30	1219.30	.95	1219.5	22.0	.7	.013
I-31	1220.30	.27	1220.5	23.0	.6	.012
				Totals=	994.0	18.89

RUN 7
GC DATA - OUTLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
Start	1157.30		1157.5	.0		
O-1	1157.43	0.00	1157.7	.2	.0	.000
O-2	1158.16	.13	1158.3	.8	.0	.001
O-3	1158.46	.22	1158.8	1.3	.1	.002
O-4	1159.16	.17	1159.3	1.8	.1	.002
O-5	1159.46	.32	1159.8	2.3	.1	.002
O-6	1200.20	.15	1200.3	2.8	.1	.003
O-7	1200.55	.31	1200.9	3.4	.1	.003
O-8	1201.25	.74	1201.4	3.9	.3	.005
O-9	1201.55	.25	1201.9	4.4	.2	.005
O-10	1202.25	0.00	1202.4	4.9	.1	.001
O-11	1202.55	0.00	1202.9	5.4	.0	.000
O-12	1203.25	.24	1203.4	5.9	.1	.001
O-13	1203.55	0.00	1203.9	6.4	.1	.001
O-14	1204.25	0.00	1204.4	6.9	.0	.000
O-15	1204.55	0.00	1204.9	7.4	.0	.000
O-16	1205.28	0.00	1205.5	8.0	.0	.000
O-17	1206.30	.20	1206.5	9.0	.1	.002
O-18	1207.30	.42	1207.5	10.0	.3	.006
O-19	1208.30	.31	1208.5	11.0	.4	.007
O-20	1209.30	.33	1209.5	12.0	.8	.014
O-21	1210.30	.41	1210.5	13.0	.4	.007
O-22	1211.30	.09	1211.5	14.0	.3	.005
O-23	1212.30	.06	1212.5	15.0	.1	.001
O-24	1213.30	.18	1213.5	16.0	.1	.002
O-25	1214.30	.53	1214.5	17.0	.4	.007
O-26	1215.30	.34	1215.5	18.0	.4	.008
O-27	1216.30	.71	1216.5	19.0	.5	.010
O-28	1217.30	.25	1217.5	20.0	.5	.009
O-29	1218.30	.58	1218.5	21.0	.4	.008
O-30	1219.30	.17	1219.5	22.0	.4	.007
O-31	1220.30	.05	1220.5	23.0	.1	.002
				Totals=	6.3	.120


RUN #7 EO INLET CONCENTRATION


RUN #7 THC CONCENTRATION


RUN #7 EO OUTLET CONCENTRATION

APPENDIX E

EXPERIMENTAL DATA
CATALYTIC OXIDATION SYSTEM
ETHYLENE OXIDE ADDITION EXPERIMENTS

NOTES TO APPENDIX E

1. GC CALCULATIONS

a. The area under the curve is the average of the current and previous points times the time interval since the GC samples are near instantaneous grab samples.

b. The EO emissions in grams are the area in ppm*min times 0.019 obtained from the equation:

$$\text{g EO} = \frac{\text{ppm } (\mu L/L) * \text{min} * 370 \text{ ft}^3/\text{min} * 28.32 \text{ L/ft}^3 * 1.83 \text{ g/L}}{10^6 \ \mu L/L}$$

The catalyst is assumed to be leak-free, thus the outlet flow is the same as the inlet flow.

c. For the water samples, the emission factor is 0.0033 times the curve area from:

$$\text{g EO} = \frac{\text{ppm (mg/L)} * \text{min} * 3.3 \text{ L/min}}{1{,}000 \text{ mg/g}}$$

2. THC CALCULATIONS

a. The THC responds to the sum of all organics. The correction from ppm as EO to Est EO (ppm) uses measured response factors for 1000 ppm mixtures of EO and CF_2Cl_2 in nitrogen. Assuming that the inlet vapor remains at 12% EO, 88% R-12 (w/w) the EO fraction would be 64% of the total signal. A moderate nonlinearity of CF_2Cl_2 response was ignored. Also, in runs 1, 4, and 7 the losses into the water probably have shifted the ratio to some extent because of the high solubility of EO and the low solubility of CF_2Cl_2.

b. The area under the curve calculation is the time from the previous reading times the logger reading in ppm. This is because the logger records the average of all scans since the previous entry. Where noise problems caused skipped points the average covers the entire period, not just the last 10 sec.

c. The same 0.019 factor for Est EO emissions is used.

3. NOTE ON FLOW MEASUREMENTS

Because of the difficulty of measuring the low delta P across the pitot, no attempt to correct the flow according to the delta P measured during each run was made. The inlet flow is assumed equal to the traverse run on June 8 (370 ft^3/min). The measurement precision is about ±50 cfm. The catalyst bed had Magnehelic gauges monitoring the pressure drop across each stage. These gauges never varied during any test.

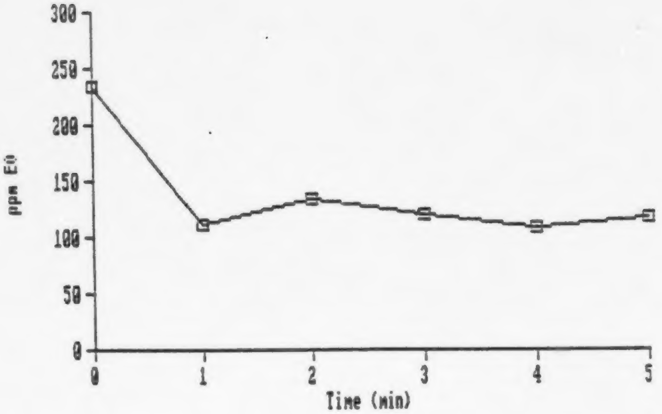
RUN 2
GC DATA - INLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min)	EO (g)
I-1	1044.00	234.15	1044.0	.0		
I-2	1045.00	112.09	1045.0	1.0	173.1	3.29
I-3	1046.00	135.08	1046.0	2.0	123.6	2.35
I-4	1047.00	121.11	1047.0	3.0	128.1	2.43
I-5	1048.00	110.19	1048.0	4.0	115.7	2.20
I-6	1049.00	117.51	1049.0	5.0	113.9	2.16
				Totals=	654.3	12.43

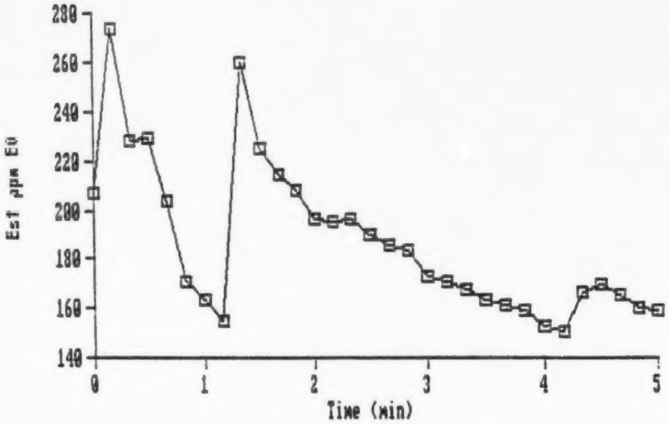
RUN 2
GC DATA - OUTLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
O-1	1044.00	.20	1044.0	.0		
O-2	1045.00	.47	1045.0	1.0	.3	.006
O-3	1046.00	0.00	1046.0	2.0	.2	.004
O-4	1047.00	0.00	1047.0	3.0	.0	.000
O-5	1048.00	.09	1048.0	4.0	.0	.001
O-6	1049.00	.20	1049.0	5.0	.1	.003
				Totals=	.8	.014

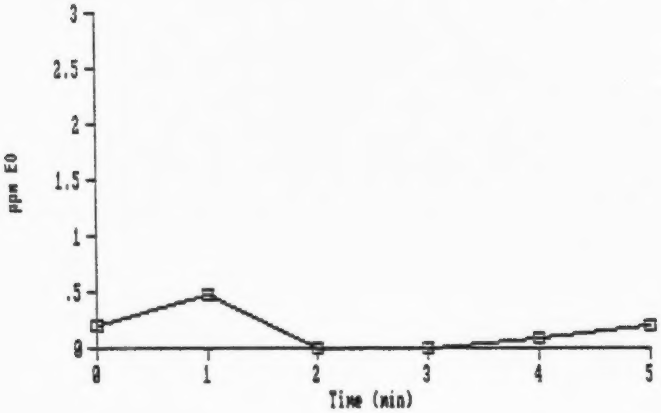
RUN #2 EO INLET CONCENTRATION



RUN #2 THC CONCENTRATION



RUN #2 EO OUTLET CONCENTRATION

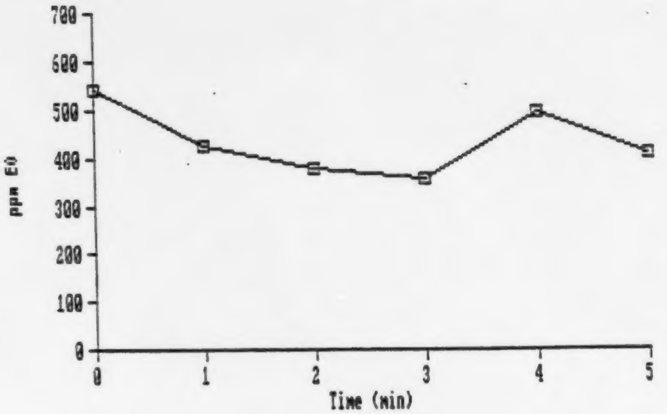


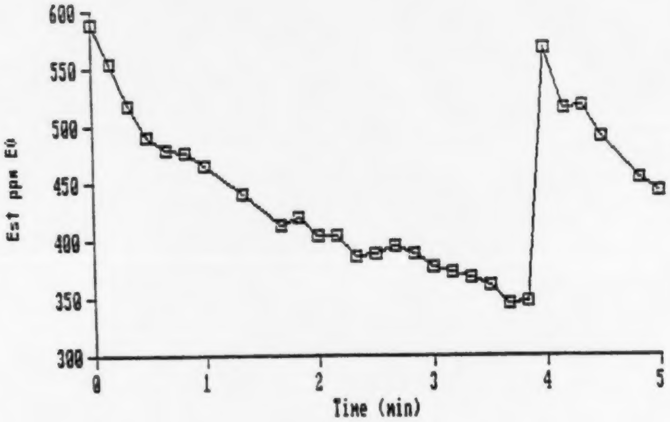
RUN 3
GC DATA - OUTLET

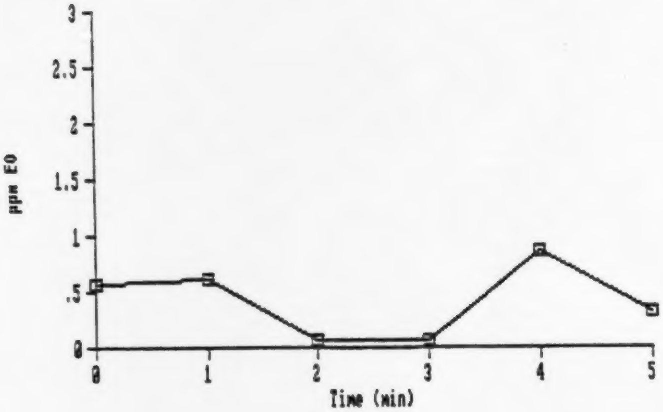
Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
O-7	1110.00	.56	1110.0	.0		
O-8	1111.00	.61	1111.0	1.0	.6	.011
O-9	1112.00	.06	1112.0	2.0	.3	.006
O-10	1113.00	.06	1113.0	3.0	.1	.001
O-11	1114.00	.86	1114.0	4.0	.5	.009
O-12	1115.00	.33	1115.0	5.0	.6	.011
				Totals=	2.0	.039

RUN 3
GC DATA - INLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min)	EO (g)
I-7	1110.00	541.67	1110.0	.0		
I-8	1111.00	425.19	1111.0	1.0	483.4	9.19
I-9	1112.00	379.39	1112.0	2.0	402.3	7.64
I-10	1113.00	358.13	1113.0	3.0	368.8	7.01
I-11	1114.00	494.48	1114.0	4.0	426.3	8.10
I-12	1115.00	410.56	1115.0	5.0	452.5	8.60
				Totals=	2133.3	40.53


RUN #3 EO INLET CONCENTRATION


RUN #3 THC CONCENTRATION

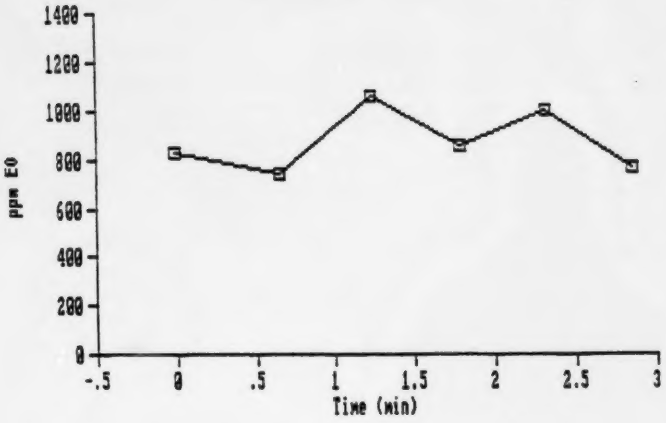

RUN #3 EO OUTLET CONCENTRATION

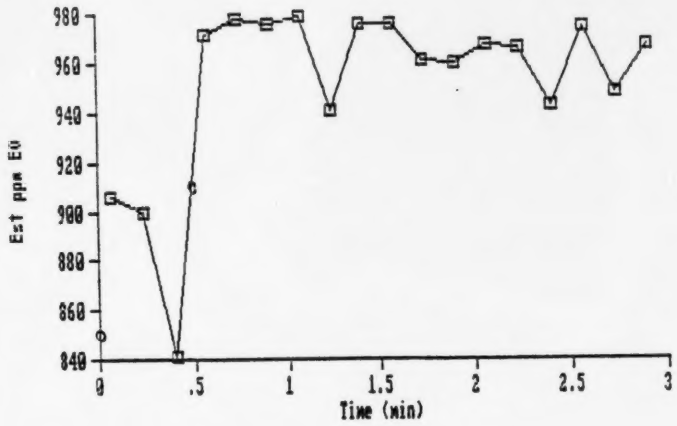
RUN 5
GC DATA - INLET

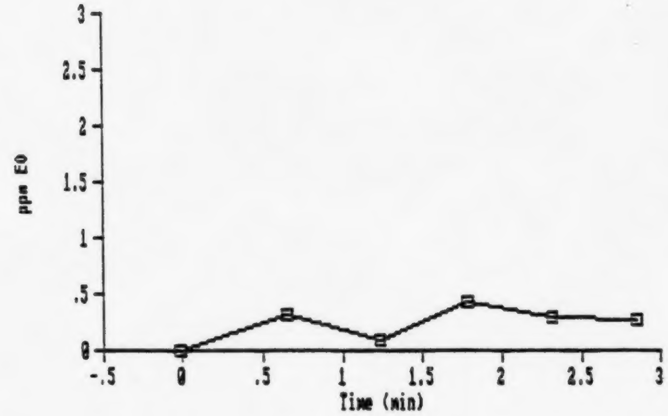
Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min)	EO (g)
I-1	939.05	832.61	939.1	-.0		
I-2	939.45	750.43	939.8	.7	527.7	10.03
I-3	940.20	1066.83	940.3	1.2	530.0	10.07
I-4	940.53	858.80	940.9	1.8	529.5	10.06
I-5	941.25	1006.97	941.4	2.3	497.5	9.45
I-6	941.57	780.08	942.0	2.9	476.5	9.05
				Totals=	2561.3	48.67

RUN 5
GC DATA - OUTLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
O-1	939.05	0.00	939.1	-.0		
O-2	939.45	.31	939.8	.7	.1	.002
O-3	940.20	.09	940.3	1.2	.1	.002
O-4	940.53	.44	940.9	1.8	.1	.003
O-5	941.25	.30	941.4	2.3	.2	.004
O-6	941.57	.27	942.0	2.9	.2	.003
				Totals=	.7	.014


RUN #5 EO INLET CONCENTRATION


RUN #5 THC CONCENTRATION


RUN #5 EO OUTLET CONCENTRATION

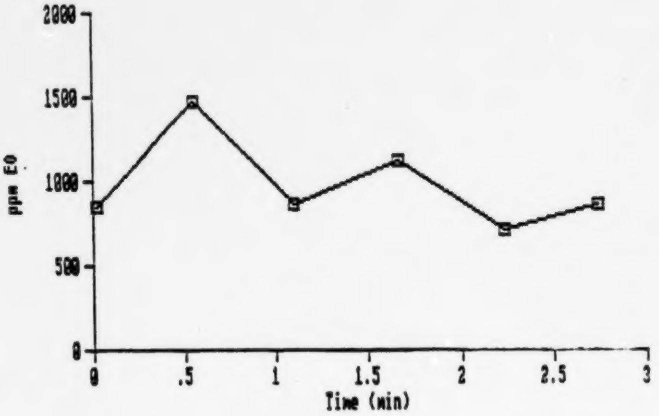
RUN 6
GC DATA - INLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min)	EO (g)
I-7	949.49	849.71	949.8	.0		
I-8	950.21	1482.43	950.4	.6	621.9	11.82
I-9	950.54	872.25	950.9	1.1	647.5	12.30
I-10	951.28	1125.50	951.5	1.7	566.0	10.75
I-11	952.02	708.87	952.0	2.2	519.7	9.88
I-12	952.32	867.70	952.5	2.7	394.1	7.49
				Totals=	2749.4	52.24

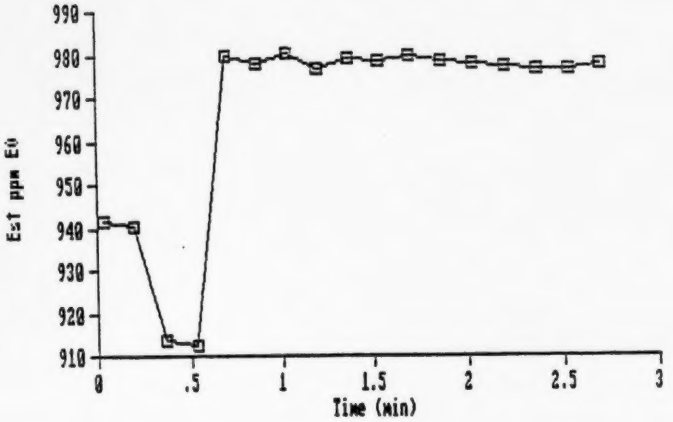
RUN 6
GC DATA - OUTLET

Sample No.	Time (min.sec)	ppm EO	Time (dec.)	Time from start	EO Area (ppm*min	EO (g)
O-7	949.49	0.00	949.8	.0		
O-8	950.21	.27	950.4	.6	.1	.001
O-9	950.54	.14	950.9	1.1	.1	.002
O-10	951.28	.06	951.5	1.7	.1	.001
O-11	952.02	.42	952.0	2.2	.1	.003
O-12	952.32	.52	952.5	2.7	.2	.004
				Totals=	.6	.012

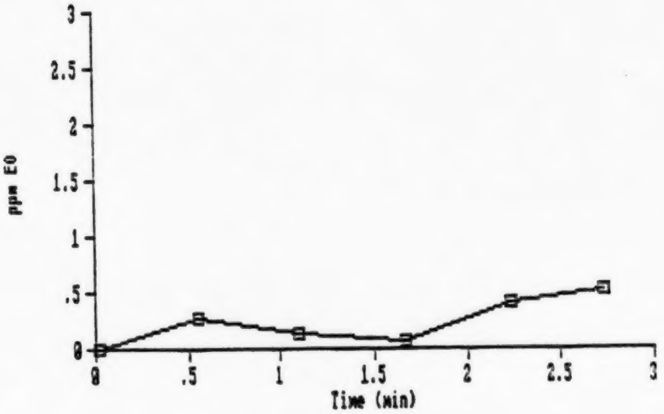
RUN #6 EO INLET CONCENTRATION



RUN #6 THC CONCENTRATION



RUN #6 EO OUTLET CONCENTRATION



APPENDIX F

EXPERIMENTAL DATA
CATALYTIC OXIDATION SYSTEM
CHLOROFLUOROCARBON DECOMPOSITION EXPERIMENTS

SUMMARY OF CHLOROFLUOROCARBON DECOMPOSITION STUDIES

Run no.	Chloride concentration (ng/mL)[a]	Impinger volume (mL)	Sample volume (dscf)	System flow rate (dscfm)[b]	Maximum chloride emissions (µg/min)	Maximum possible Freon decomposition (µg/min)[c]	Sampling time (min)	Maximum possible Freon decomposition (µg)	Freon input (kg)[d]	Maximum Freon decomposition (%)	Maximum catalyst temperature (°F)
1	< 200	20	1.5	370	< 5	< 18	28.0	< 520	1.20	$< 4 \times 10^{-5}$	283
2	< 200	20	1.1		< 4	< 13	5.0	< 67	0.104	$< 6 \times 10^{-5}$	287
4	< 200	20	1.3		< 5	< 16	25.8	< 400	1.21	$< 3 \times 10^{-5}$	299
5	< 200	20	0.46		< 2	< 5.8	2.8	< 16	0.407	$< 4 \times 10^{-6}$	311
7	< 200	20	0.92		< 3	< 12	22.8	< 260	1.24	$< 2 \times 10^{-5}$	282

[a] No chloride was detected in the samples. These results are calculated using the detection limit concentration of 200 ng/mL.

[b] See note on flow measurements in Appendix D.

[c] The assumption of one Cl^- per CF_2Cl_2 molecule was used to calculate possible CF_2Cl_2 emissions.

[d] The CF_2Cl_2 input values for the sterilizer discharge tests, Runs 1, 4, 7 were determined by measuring a change in cylinder weight and correcting for 12/88% by weight EO/CF_2Cl_2 concentrations. Since a large portion of the EO was lost to the water discharge, and some of the 12/88 mixture may have been lost to the vent, the percent decomposition values may be artificially low because it is not possible to quantitate the amount of CF_2Cl_2 input into the catalyst. The CF_2Cl_2 input values for the steady state tests, Runs 2, 5, were in proportion (12/88) to the detected EO input levels.

APPENDIX G

EXPERIMENTAL DATA
ACID SCRUBBER SYSTEM
STERILIZER DISCHARGE STUDIES

NOTES TO APPENDIX G

The dry gas meter readings are converted to flow rates by correcting to scfm using the meter calibration factor, temperature, pressure, and interval to previous reading:

$$\text{Flow rate (scfm)} = \frac{\text{(current DGM - previous DGM [ft}^3\text{])}}{\text{time from previous reading (min)}} \times M_f \times \frac{528}{460 + T} \times \frac{\text{pressure}}{29.92}$$

During run 6:

$$M_f = 0.9131 \qquad \text{Flow rate (scfm)} = \frac{0.8999 \times \text{net ft}^3}{\text{net time}}$$

$$T = 82°\text{F}$$

$$P = 30.20 + \frac{1 \text{ in. w.c.}}{13.6} = 30.27$$

Inlet Flows

For the inlet, the same flow rate equation is used, but with an additional term to correct for the EO absorbed = outlet flow $\times \dfrac{100}{(100 - \%\ \text{EO})}$

Outlet Emissions

$$\text{EO (mg)} = \frac{\text{flow rate (scfm)} \times 28.32\ \text{L/ft}^3 \times 1.83\ \text{g/L}}{10^3\ \text{mL/L}} \times \text{ppm} \times \text{min}$$

or flow rate x ppm x min x 0.0518

Inlet Emissions

$$\text{EO (g)} = \frac{\text{flow rate (scfm} \times 28.32\ \text{L/ft}^3 \times 1.83\ \text{g/L} \times \% \times \text{min)}}{100}$$

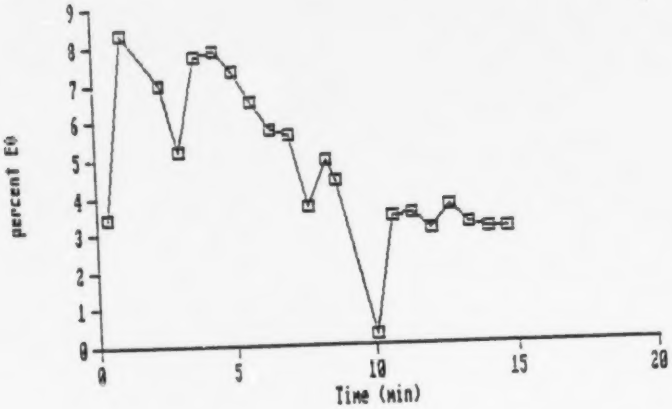
or flow rate x % EO x min x 0.518

RUN 4
GC DATA - INLET

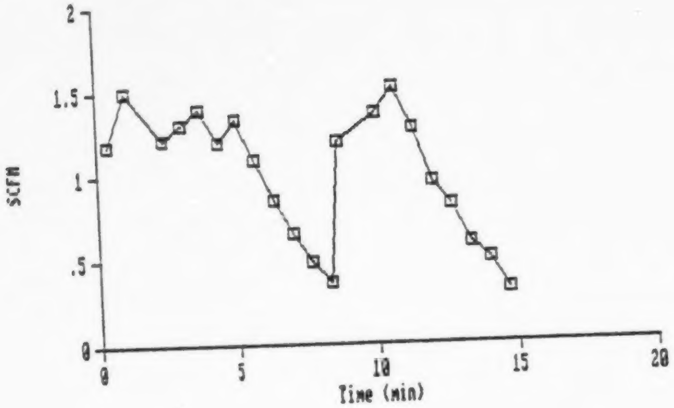
Sample No.	Time (min.sec)	DGM (cu. ft.)	percent EO	Time from start	Gas Flow (SCFM)	EO (g)	Rate (g/min)
Start	1328.49	419.43		.0			
I-1	1329.10	419.87	3.40	.4	1.19	.37	1.1
I-2	1329.50	420.87	8.38	1.0	1.50	3.05	4.6
I-4	1331.10	422.52	6.99	2.4	1.22	6.48	4.9
I-5	1331.50	423.42	5.23	3.0	1.31	2.76	4.1
I-6	1332.30	424.36	7.72	3.7	1.40	3.13	4.7
I-7	1333.10	425.16	7.87	4.4	1.19	3.22	4.8
I-8	1333.50	426.06	7.29	5.0	1.34	3.50	5.2
I-9	1334.30	426.80	6.47	5.7	1.09	2.59	3.9
I-10	1335.10	427.38	5.75	6.4	.85	1.79	2.7
I-11	1335.50	427.83	5.58	7.0	.66	1.28	1.9
I-12	1336.30	428.17	3.70	7.7	.49	.78	1.2
I-13	1337.10	428.42	4.91	8.4	.36	.54	.8
I-14	1345.30	428.84	4.41	8.7	1.21	.97	2.9
I-16	1346.50	430.82	.24	10.0	1.37	2.19	1.6
I-17	1347.30	431.89	3.43	10.7	1.52	.97	1.4
I-18	1348.10	432.79	3.47	11.4	1.28	1.53	2.3
I-19	1348.50	433.47	3.08	12.0	.97	1.09	1.6
I-20	1349.30	434.05	3.71	12.7	.83	.97	1.5
I-21	1350.10	434.47	3.24	13.4	.60	.72	1.1
I-22	1350.50	434.82	3.07	14.0	.50	.54	.8
I-23	1351.30	435.04	3.07	14.7	.31	.33	.5
				Totals=		38.79	

RUN 5
GC DATA - INLET

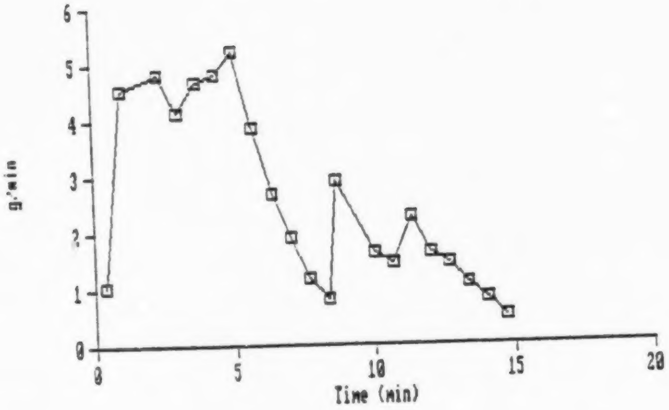
Sample No.	Time (min.sec)	DGM (cu. ft.)	percent EO	Time from start	Gas Flow (SCFM)	EO (g)	Rate (g/min)
Start	1002.38	443.80					
I-1	1004.00	444.93	10.26	1.4	.81	3.02	2.2
I-2	1004.40	445.78	10.92	2.1	1.29	4.73	7.1
I-3	1005.20	446.62	10.10	2.7	1.27	4.60	6.9
I-4	1006.00	447.47	8.08	3.4	1.25	3.93	5.9
I-5	1006.40	448.35	9.73	4.1	1.32	4.06	6.1
I-6	1007.20	449.20	9.46	4.7	1.27	4.22	6.3
I-7	1008.00	449.98	8.90	5.4	1.16	3.68	5.5
I-8	1008.40	450.60	8.24	6.1	.92	2.71	4.1
I-9	1009.20	451.06	7.21	6.7	.67	1.79	2.7
I-10	1010.00	451.40	6.55	7.4	.49	1.17	1.8
I-11	1010.40	451.65	1.92	8.1	.35	.51	.8
I-12	1011.07	451.81	6.12	8.5	.34	.32	.7
I-13	1019.10	452.12	5.39	9.1	.54	.88	1.6
I-14	1019.50	453.07	6.22	9.7	1.37	2.75	4.1
I-15	1020.30	454.08	5.02	10.4	1.44	2.80	4.2
I-16	1021.10	455.17	5.20	11.1	1.56	2.75	4.1
I-17	1021.50	456.06	4.45	11.7	1.26	2.10	3.2
I-18	1022.30	456.74	4.95	12.4	.97	1.57	2.4
I-19	1023.10	457.29	4.43	13.1	.78	1.26	1.9
I-20	1023.50	457.73	5.42	13.7	.63	1.07	1.6
I-22	1025.10	458.26	4.99	15.1	.38	1.36	1.0
				Totals=		51.30	



RUN #4 EO INLET CONCENTRATION

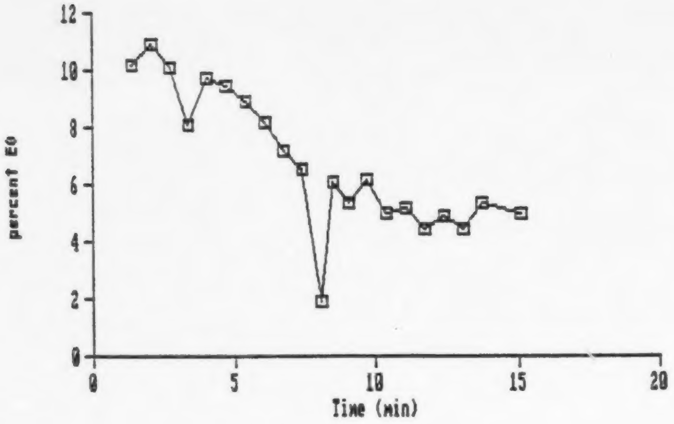


RUN #4 INLET FLOW RATE

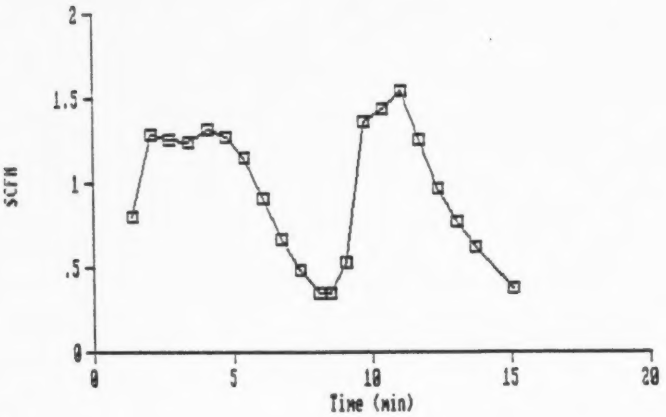


RUN #4 EO INLET EMISSION RATE

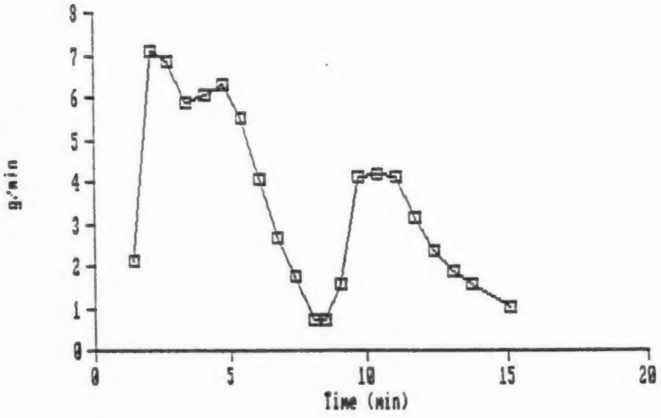
RUN #5 EO INLET CONCENTRATION



RUN #5 INLET FLOW RATE



RUN #5 EO INLET EMISSION RATE



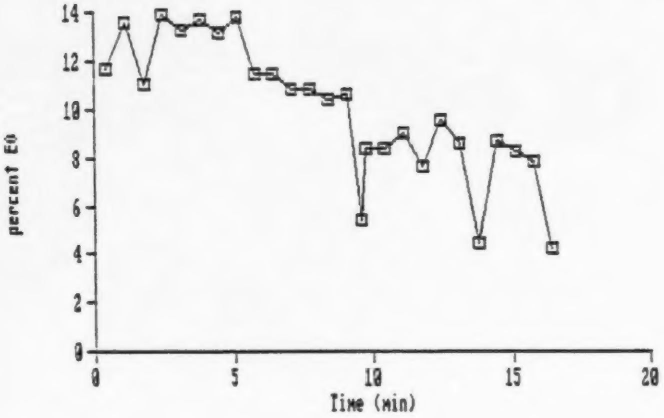
RUN 6
GC DATA - INLET

Sample No.	Time (min.sec)	DGM (cu. ft.)	percent EO	Time from start	Gas Flow (SCFM)	EO (g)	Rate (g/min)
Start	1433.26	485.34					
I-1	1433.50	485.82	11.76	.4	1.13	1.49	3.4
I-2	1434.30	486.69	13.60	1.1	1.36	5.95	8.9
I-3	1435.10	487.53	11.12	1.8	1.28	5.45	8.2
I-4	1435.50	488.36	13.95	2.4	1.30	5.64	8.5
I-5	1436.30	489.24	13.27	3.1	1.37	6.44	9.7
I-6	1437.10	490.15	13.70	3.8	1.42	6.63	9.9
I-7	1437.50	491.02	13.16	4.4	1.35	6.27	9.4
I-8	1438.30	491.87	13.88	5.1	1.33	6.22	9.3
I-9	1439.10	492.62	11.52	5.8	1.14	5.02	7.5
I-10	1439.50	493.14	11.55	6.4	.79	3.16	4.7
I-11	1440.30	493.54	10.82	7.1	.61	2.34	3.5
I-12	1441.10	493.85	10.91	7.8	.47	1.76	2.6
I-13	1441.50	494.18	10.40	8.4	.50	1.83	2.7
I-14	1442.30	494.26	10.64	9.1	.12	.44	.7
I-15	1443.00	494.32	5.39	9.6	.11	.24	.5
I-16	1450.40	494.53	8.41	9.8	1.24	.74	4.4
I-17	1451.20	495.46	8.46	10.4	1.37	3.99	6.0
I-18	1452.00	496.50	9.09	11.1	1.54	4.68	7.0
I-19	1452.40	497.57	7.65	11.8	1.56	4.52	6.8
I-20	1453.20	498.44	9.55	12.4	1.30	3.86	5.8
I-21	1454.00	499.13	8.63	13.1	1.02	3.20	4.8
I-22	1454.40	499.67	4.51	13.8	.76	1.73	2.6
I-23	1455.20	500.08	8.77	14.4	.61	1.39	2.1
I-24	1456.00	500.43	8.34	15.1	.52	1.52	2.3
I-25	1456.40	500.71	7.90	15.8	.41	1.15	1.7
I-26	1457.20	500.89	4.21	16.4	.25	.53	.8
I-30	1509.15	502.30	3.94	16.9	3.17	2.79	6.7
I-31	1510.15	504.90	3.46	17.9	2.42	4.65	4.6
I-32	1511.15	507.90	3.28	18.9	2.79	4.87	4.9
I-33	1512.15	510.70	1.64	19.9	2.56	3.26	3.3
I-34	1513.15	513.60	3.48	20.9	2.70	3.59	3.6
I-35	1514.15	516.45	3.28	21.9	2.65	4.64	4.6
I-36	1519.15	530.90	2.96	26.9	2.68	21.66	4.3
I-37	1524.15	545.50	2.84	31.9	2.70	20.31	4.1
I-38	1529.15	560.00	2.61	36.9	2.68	18.91	3.8
I-39	1534.15	574.50	2.39	41.9	2.67	17.31	3.5
I-40	1538.30	587.50	2.23	46.1	2.82	14.32	3.4
				Totals=		202.49	

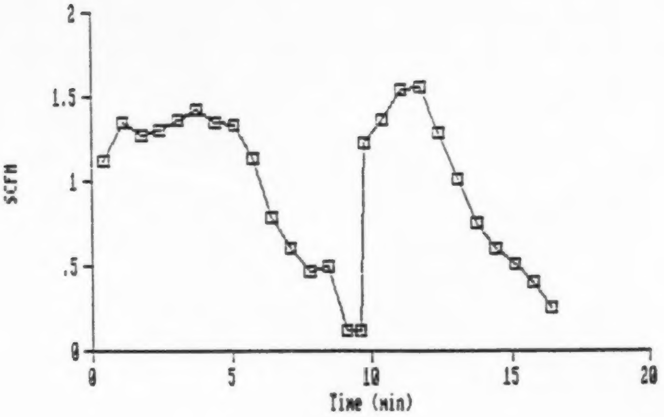
RUN 6
GC DATA - OUTLET

Sample No.	Time (min.sec)	DGM (cu. ft.)	ppm EO	Time from start	Gas Flow (SCFM)	EO (mg)	Rate (mg/min)
Start	1433.26	485.34					
O-1	1433.50	485.82	24.42	.4	1.00	.273	.63
O-2	1434.30	486.69	13.87	1.1	1.17	.776	1.16
O-3	1435.10	487.53	11.96	1.8	1.13	.506	.76
O-4	1435.50	488.36	14.10	2.4	1.12	.504	.76
O-5	1436.30	489.24	8.65	3.1	1.19	.467	.70
O-6	1437.10	490.15	8.95	3.8	1.23	.373	.56
O-7	1437.50	491.02	4.65	4.4	1.17	.276	.41
O-8	1438.30	491.87	4.03	5.1	1.15	.172	.26
O-9	1439.10	492.62	3.13	5.8	1.01	.125	.19
O-10	1439.50	493.14	3.28	6.4	.70	.078	.12
O-11	1440.30	493.54	3.11	7.1	.54	.060	.09
O-12	1441.10	493.85	3.98	7.8	.42	.051	.08
O-13	1441.50	494.18	5.61	8.4	.45	.074	.11
O-14	1442.30	494.26	5.01	9.1	.11	.020	.03
O-15	1443.00	494.32	7.70	9.6	.11	.018	.04
O-16	1450.40	494.53	3.78	9.8	1.13	.056	.34
O-17	1451.20	495.46	3.43	10.4	1.26	.156	.23
O-18	1452.00	496.50	.93	11.1	1.40	.106	.16
O-19	1452.40	497.57	1.12	11.8	1.44	.051	.08
O-20	1453.20	498.44	.90	12.4	1.17	.041	.06
O-21	1454.00	499.13	.63	13.1	.93	.025	.04
O-22	1454.40	499.67	1.70	13.8	.73	.029	.04
O-23	1455.20	500.08	2.00	14.4	.55	.035	.05
O-24	1456.00	500.43	.94	15.1	.47	.024	.04
O-25	1456.40	500.71	3.69	15.8	.38	.030	.05
O-26	1457.20	500.89	8.47	16.4	.24	.051	.08
				Totals=		4.38	

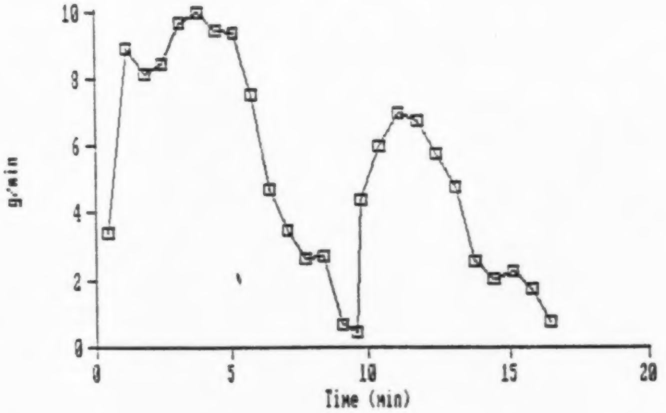
RUN #6 EO INLET CONCENTRATION



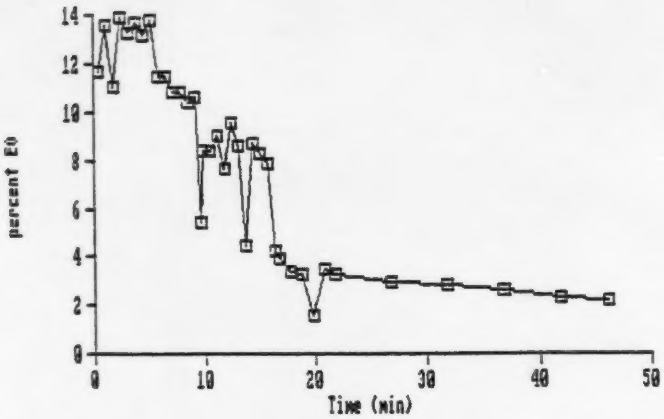
RUN #6 INLET FLOW RATE



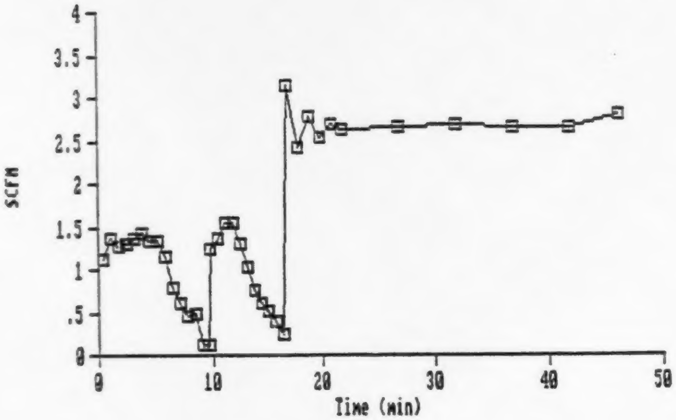
RUN #6 EO INLET EMISSION RATE



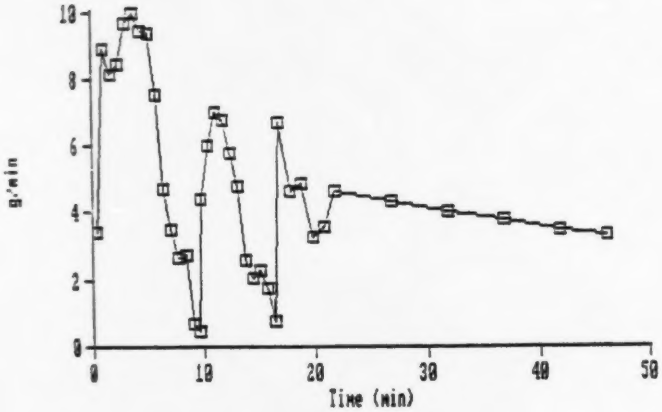
RUN #6 EO INLET CONCENTRATION



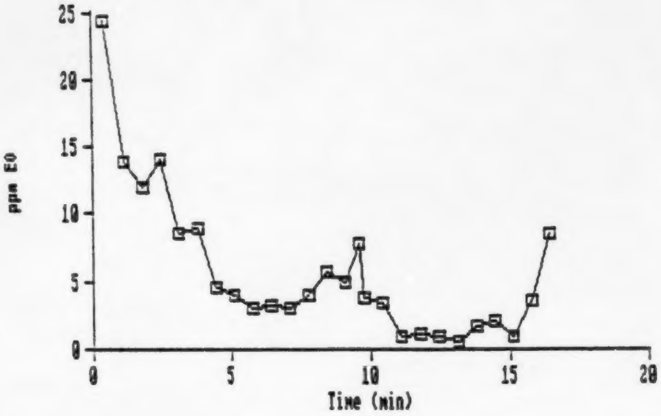
RUN #6 INLET FLOW RATE



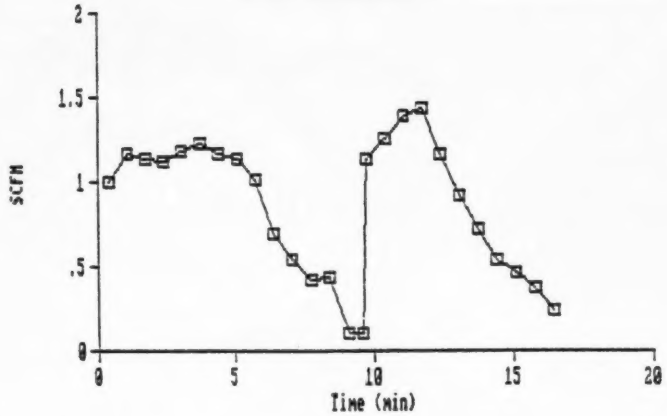
RUN #6 EO INLET EMISSION RATE



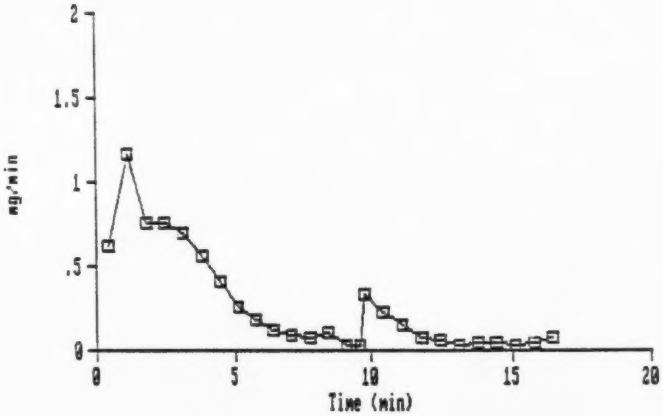
RUN #6 EO OUTLET CONCENTRATION



RUN #6 OUTLET FLOW RATE

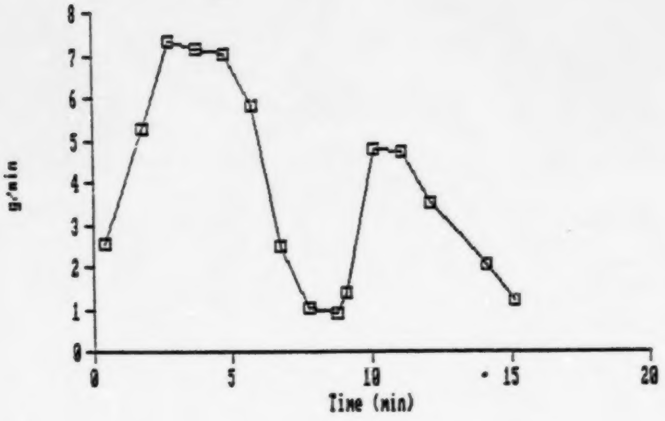


RUN #6 EO OUTLET EMISSION RATE

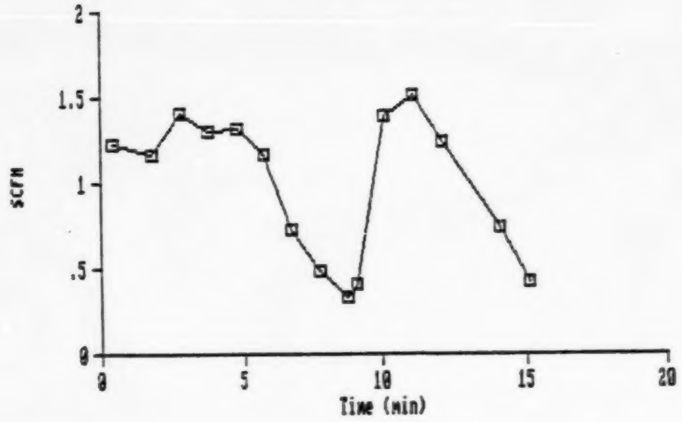


RUN 7
GC DATA - INLET

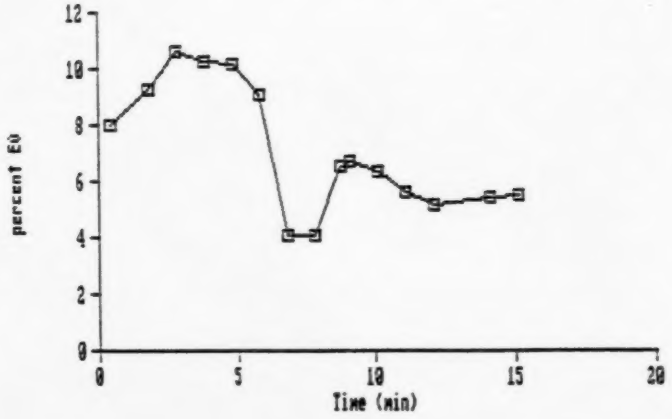
Sample No.	Time (min.sec)	DGM (cu. ft.)	percent EO	Time from start	Gas Flow (SCFM)	EO (g)	Rate (g/min)
Start	954.56	661.51					
I-1	955.20	662.05	8.07	.4	1.23	1.11	2.6
I-2	956.40	663.62	9.27	1.8	1.18	7.05	5.3
I-3	957.40	665.02	10.66	2.8	1.42	7.34	7.3
I-4	958.40	666.32	10.33	3.8	1.32	7.15	7.1
I-5	959.40	667.63	10.20	4.8	1.32	7.04	7.0
I-6	1000.40	668.80	9.10	5.8	1.17	5.84	5.8
I-7	1001.40	669.57	4.11	6.8	.73	2.49	2.5
I-8	1002.40	670.09	4.13	7.8	.49	1.05	1.1
I-9	1003.40	670.43	6.56	8.8	.33	.91	.9
I-10	1011.30	670.57	6.79	9.1	.41	.47	1.4
I-11	1012.30	672.02	6.40	10.1	1.41	4.80	4.8
I-12	1013.30	673.60	5.69	11.1	1.52	4.76	4.8
I-13	1014.30	674.91	5.16	12.1	1.25	3.52	3.5
I-15	1016.30	676.47	5.44	14.1	.75	4.11	2.1
I-16	1017.30	676.91	5.55	15.1	.42	1.20	1.2
				Totals=		58.84	



RUN #7 EO INLET EMISSION RATE



RUN #7 INLET FLOW RATE



RUN #7 EO INLET CONCENTRATION

APPENDIX H

EXPERIMENTAL DATA
ACID SCRUBBER SYSTEM
ETHYLENE OXIDE ADDITION STUDIES

NOTES TO APPENDIX H

The dry gas meter readings are converted to flow rates by correcting to scfm using the meter calibration factor, temperature, pressure, and interval to previous reading:

$$\text{Flow rate (scfm)} = \frac{\text{(current DGM - previous DGM [ft}^3\text{])}}{\text{time from previous reading (min)}} \times M_f \times \frac{528}{460 + T} \times \frac{\text{pressure}}{29.92}$$

During run 6:

$M_f = 0.9131$

$T = 82°F$

$$\text{Flow rate (scfm)} = \frac{0.8999 \times \text{net ft}^3}{\text{net time}}$$

$$P = 30.20 + \frac{1 \text{ in. w.c.}}{13.6} = 30.27$$

Inlet Flows

For the inlet, the same flow rate equation is used, but with an additional term to correct for the EO absorbed = outlet flow $\times \frac{100}{(100 - \%\ \text{EO})}$

Outlet Emissions

$$\text{EO (mg)} = \frac{\text{flow rate (scfm)} \times 28.32\ \text{L/ft}^3 \times 1.83\ \text{g/L}}{10^3\ \text{mL/L}} \times \text{ppm} \times \text{min}$$

or flow rate x ppm x min x 0.0518

Inlet Emissions

$$\text{EO (g)} = \frac{\text{flow rate (scfm} \times 28.32\ \text{L/ft}^3 \times 1.83\ \text{g/L} \times \% \times \text{min)}}{100}$$

or flow rate x % EO x min x 0.518

RUN 1
GC DATA - INLET

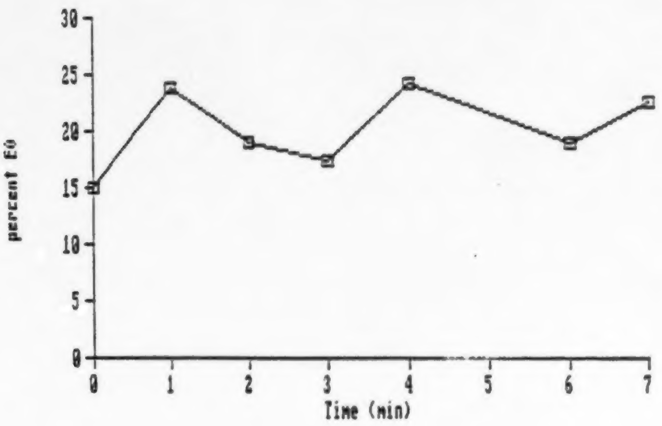
Sample No.	Time (min.sec)	DGM (cu. ft.)	percent EO	Time from start	Gas Flow (SCFM)	EO (g)	Rate (g/min)
I-1	1058.00	302.02	15.00	.0			
I-2	1059.00	304.23	24.00	1.0	2.63	26.52	26.5
I-3	1100.00	306.56	19.22	2.0	2.60	29.15	29.1
I-4	1101.00	308.76	17.55	3.0	2.41	22.94	22.9
I-5	1102.00	310.91	24.37	4.0	2.57	27.86	27.9
I-7	1104.00	315.31	19.23	6.0	2.46	55.54	27.8
I-8	1105.00	317.53	22.80	7.0	2.60	28.26	28.3
				Totals=		190.27	

RUN 2
GC DATA - INLET

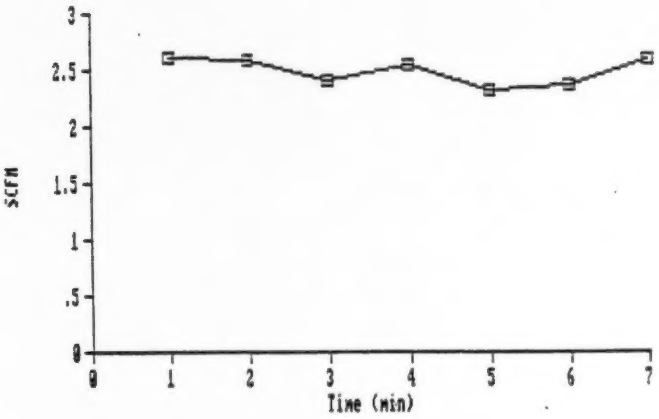
Sample No.	Time (min.sec)	DGM (cu. ft.)	percent EO	Time from start	Gas Flow (SCFM)	EO (g)	Rate (g/min)
I-1	1349.00	326.70	22.08	.0			
I-2	1350.00	328.98	22.67	1.0	2.66	30.85	30.9
I-3	1351.00	331.06	19.22	2.0	2.32	25.22	25.2
				Totals=		56.07	

RUN 3
GC DATA - INLET

Sample No.	Time (min.sec)	DGM (cu. ft.)	percent EO	Time from start	Gas Flow (SCFM)	EO (g)	Rate (g/min)
I-1	1419.00	335.96	21.88	.0			
I-2	1420.00	338.26	21.05	1.0	2.67	29.71	29.7
I-3	1421.00	340.31	23.49	2.0	2.46	28.35	28.4
I-4	1422.00	342.59	22.29	3.0	2.69	31.91	31.9
I-5	1423.00	344.78	24.38	4.0	2.66	32.11	32.1
I-6	1424.00	346.82	21.57	5.0	2.39	28.40	28.4
I-7	1425.00	349.05	23.51	6.0	2.67	31.22	31.2
I-8	1426.00	351.26	22.65	7.0	2.62	31.33	31.3
				Totals=		213.04	



RUN #1 EO INLET CONCENTRATION



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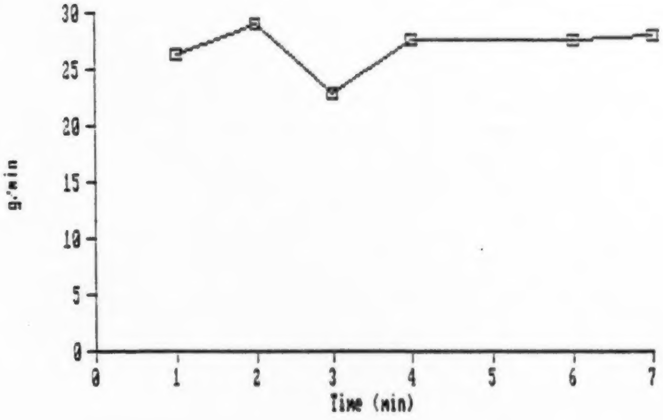
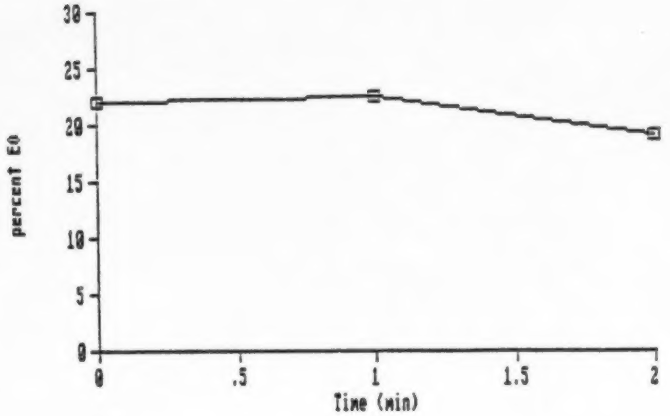


RUN #1 EO INLET EMISSION RATE

RUN #2 EO INLET CONCENTRATION



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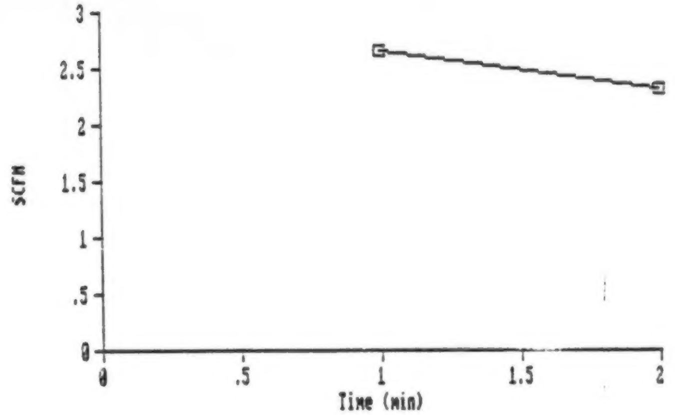

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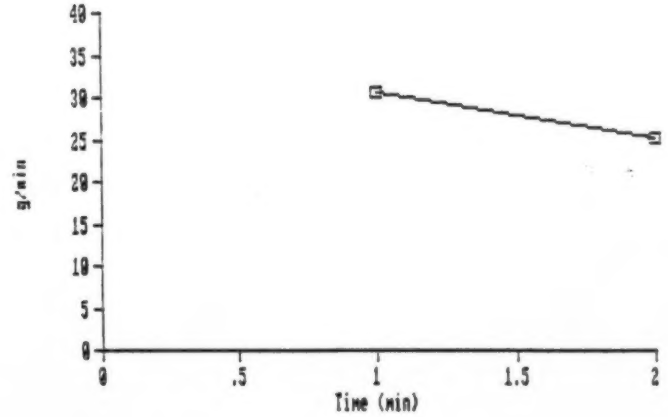
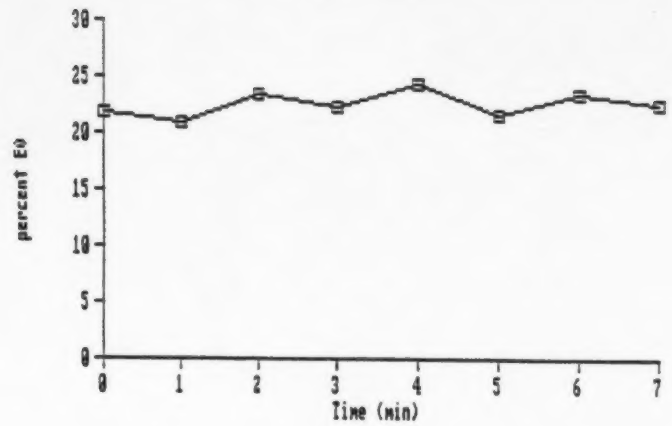
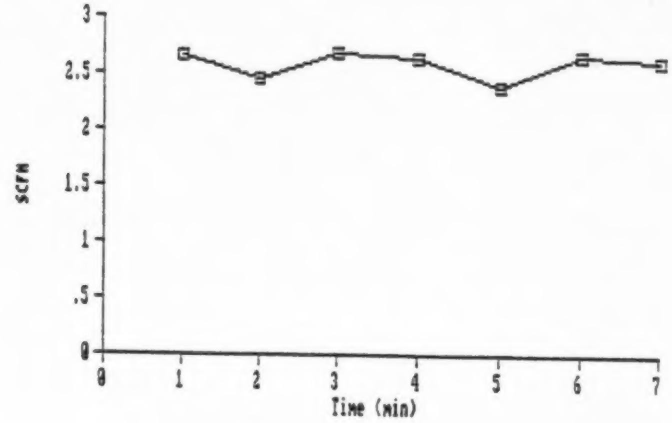


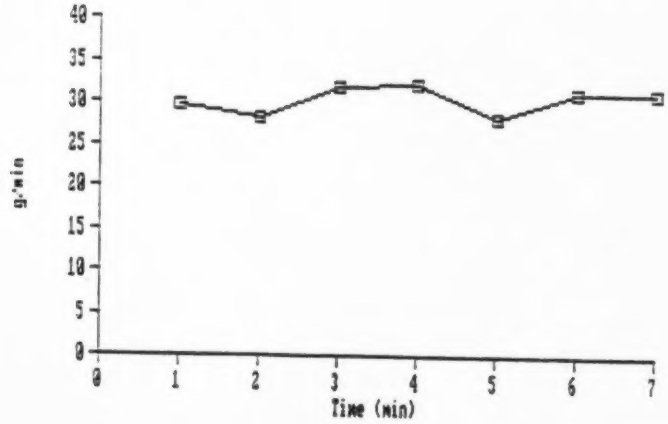
RUN #3 EO INLET CONCENTRATION



RUN #3 INLET FLOW RATE



RUN #3 EO INLET EMISSION RATE



APPENDIX I

QUALITY CONTROL EVALUATION REPORT

APPENDIX I
September 23, 1987
Project No. 8691-L(10)

ETHYLENE OXIDE CONTROL TECHNOLOGY DEVELOPMENT FOR HOSPITALS STERILIZERS

This report summarizes the independent QA/QC activities that were performed in conjunction with this project.

The experimental work was conducted at two test sites for the evaluation of a catalytic oxidation system and an acid-scrubber system. A separate Quality Assurance Project Plan (QAP) was written for both test sites.

The experimental work was performed by Laurie Cone and Dannette Shaw under the direction of George Scheil and Al Meiners (Project Leader). The Quality Assurance Coordinator (QAC) for this project was Dennis Hooton; Shri Kulkarni and Anne Worth of the Center for Environmental Quality Assurance, Research Triangle Institute, performed audits for the U. S. EPA at the first test site.

I. Performance Audit Sample Results

A. Ethylene Oxide

An independent performance audit sample was analyzed at the Paoli test site by gas chromatography. The audit sample was a CL cylinder of ethylene oxide in nitrogen, procured by the QAC from Scott Specialty Gases; label information indicated that it was prepared on 5/22/87 and certified at ±2% accuracy. The manufacturer's listed concentration was removed from the label, a MRI sample identification number was assigned and labeled on the cylinder, then it was given to the field crew and transported to the test site for analysis. Results were initially reported via phone from the test site to confirm that the results met data quality objectives for accuracy; the audit results were reported in writing by the analysts upon their return to Kansas City.

Overall, precision and accuracy results were good for the analysis of the MRI audit cylinder. Data Quality Objectives (DQOs) for the analysis of ethylene oxide by gas chromatography were 10% RPD (range % deviation) for precision, and 90% to 110% of the "true" value for accuracy. QC results indicated accuracies of 98% and 92% for Detectors A and B, respectively; precision was demonstrated from replicate injections analysis to be 3% RPD for Detector A and 24% RPD for Detector B. A complete summary of the audit sample results is shown in Table I-1.

TABLE I-1. ACCURACY AND PRECISION RESULTS FOR THE MRI ETHYLENE OXIDE AUDIT CYLINDER

MRI sample no.: 04428
Date analyzed: 6/4/87

Replicate analysis	Detector A Concentration found (ppm)*	Detector B Concentration found (ppm)
1	478.8	476.9
2	484.9	406.3
3	489.9	490.8
4	475.9	397.8
5	480.3	489.5
6	-	407.3
7	-	508.4
Mean:	482 ppm	454 ppm
Precision:	3% RPD	24% RPD
Expected Concentration:	492 ppm	492 ppm
Accuracy:	98%	92%

* ppm = v/v.

Precision of Detector B was outside the DQO and indicates that instrument performance was simply not as good as it was for Detector A. These precision results are also reflected in the performance of the detectors when the EPA audit cylinder was analyzed.

As indicated in RTI's audit report of July 31, 1987, some of the performance checks of the Paoli audit were outside the DQOs. The two GC detectors (A and B) were checked by analyzing samples from an EPA audit cylinder. Results of the analyses showed that precisions were demonstrated to be 1.3% RPD for Detector A and 11.2% RPD for Detector B. Accuracy values were calculated to be 87.3% and 104.1% for Detectors A and B, respectively. Comments provided by the project officer indicate that, although the two values exceeded the DQOs in the project plan, the data obtained indicates that the objective of the project was not affected by the deviation. The typical maximum concentration in the inlet stream is 430 ppm whereas the typical maximum concentration in the outlet is 0.74 ppm. The reduction in the EO levels is so significant that the deviation in the precision and accuracy by a factor of 2 will not affect the results that indicate better than 99% control of EO in the emission stream.

B. Chlorides

Two performance audit samples were prepared for chloride analysis by ion chromatography by diluting a potassium chloride reference standard solution, certified by an independent laboratory, with project supplied Table 1 eluent (3 mM $NaHCO_3$/2.4 mM Na_2CO_3). Concentrations of the performance samples were not disclosed to the analyst; however, based on discussions with the analyst, the concentration range for preparing the performance samples was lowered to 0 to 3 ppm (µg/mL) from the originally planned 0 to 50 ppm because of the nondetected levels of chlorides found in the test samples.

Results of the duplicate analyses of the performance samples indicated 85% accuracy for the 1.42 ppm sample and 86% accuracy for the 2.83 ppm sample. Precision found for the duplicate analyses were better than or equal to 2% RPD (range % deviation). The accuracy results do not meet the objectives listed in Table 5-1 of the QAP (April 28, 1987), i.e., ±5% of the expected value. Results for the chloride performance samples are presented in Table I-2.

TABLE I-2. ACCURACY AND PRECISION RESULTS FOR CHLORIDE PERFORMANCE SAMPLES

Date analyzed: 6/24/87

Replicate analysis	Sample no. 04430 concentration found (ppm)*	Sample no. 04431 concentration found (ppm)
1	2.41	1.20
2	2.45	1.21
Mean:	2.43 ppm	1.21 ppm
Precision:	2% RPD	1% RPD
Expected Concentration:	2.83 ppm	1.42 ppm
Accuracy:	86%	85%

* ppm = µg/mL.

II. Data and Systems Audits

The draft final report and supporting data and records were received by the QAC on September 15, 1987, for review. Selected data were chosen at random to check for systematic errors and traceability, these included:

Calculations for Run 1 of the GC sterilizer discharge studies, Run 2 of the GC ethylene oxide addition study, and the calibration data from June 9, 1987.

A systems audit on the chloride analyses by ion chromatography was conducted on June 24, 1987. The analyst had completed specialized training in ion chromatography, and was performing the work in accordance with the protocols specified in the QAP. The standard data used for establishing the calibration curve was also verified.

In general, there were no major problems found with the GC or ion chromatographic data that were inspected.

Clarification statements were provided in the project records about the data reduction procedures used for calculating ethylene oxide results, made necessary because of the very low levels of ethylene oxide found in the inlet samples. Results were calculated using the formula defined by the analyst as the "zero-intercept LLSQ fit" equation, and expressed as:

$$\sum \frac{x_i y_i}{\Sigma x_i^2}$$

References were provided for the project records to support the use of this method of calculation.

III. Conclusion

Based on observations and results of the QA review and performance audits, the work was performed by qualified personnel, in accordance with the project quality assurance plan.

MIDWEST RESEARCH INSTITUTE

Dennis Hooton
Quality Assurance Coordinator